Consultative Committee for Space Data Systems

RECOMMENDATION FOR SPACE DATA SYSTEM STANDARDS

TELECOMMAND

PART 2
DATA ROUTING SERVICE

ARCHITECTURAL SPECIFICATION

CCSDS 202.0-B-1

BLUE BOOK

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TELECOMMAND

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This Recommendation reflects the consensus technical agreement of the following member Agencies of the Consultative Committee for Space Data Systems (CCSDS):

- Centre National D'Etudes Spatiales (CNES)/France.
- Deutsche Forschungs-u. Versuchsanstalt fuer Luft und Raumfahrt e.V (DFVLR)/ West Germany.
- European Space Agency (ESA)/Europe.
- Indian Space Research Organization (ISRO)/India.
- Instituto de Pesquisas Espaciais (INPE)/Brazil.
- National Aeronautics and Space Administration (NASA)/USA.
- National Space Development Agency of Japan (NASDA)/Japan.

The following observer Agencies also concur with this Recommendation:

- British National Space Centre (BNSC)/United Kingdom.
- Chinese Academy of Space Technology (CAST)/People's Republic of China.
- Department of Communications, Communications Research Centre (DOC-CRC)/Canada.

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STATEMENT OF INTENT

The Consultative Committee for Space Data Systems (CCSDS) is an organization officially established by the management of member space Agencies. The Committee meets periodically to address data systems problems that are common to all participants, and to formulate sound technical solutions to these problems. Inasmuch as participation in the CCSDS is completely voluntary, the results of Committee actions are termed **RECOMMENDATIONS** and are not considered binding on any Agency.

This RECOMMENDATION is issued by, and represents the consensus of, the CCSDS Plenary body. Agency endorsement of this RECOMMENDATION is entirely voluntary. Endorsement, however, indicates the following understandings:

- Whenever an Agency establishes a CCSDS-related STANDARD, this STANDARD will be in accord with the relevant RECOMMENDATION. Establishing such a STANDARD does not preclude other provisions which an Agency may develop.

- Whenever an Agency establishes a CCSDS-related STANDARD, the Agency will provide other CCSDS member Agencies with the following information:

  -- The STANDARD itself.

  -- The anticipated date of initial operational capability.

  -- The anticipated duration of operational service.

- Specific service arrangements shall be made via memoranda of agreement. Neither this RECOMMENDATION nor any ensuing STANDARD is a substitute for a memorandum of agreement.

No later than five years from its date of issuance, this Recommendation will be reviewed by the CCSDS to determine whether it should: (1) remain in effect without change; (2) be changed to reflect the impact of new technologies, new requirements, or new directions; or (3) be retired or cancelled.

FOREWORD

This document, which is a technical Recommendation prepared by the Consultative Committee for Space Data Systems (CCSDS), is intended for use by participating space Agencies in their development of space telecommand systems.

This Recommendation allows the implementing organizations within each Agency to proceed coherently with the development of compatible Standards for the flight and ground systems that are within their cognizance. Agency Standards derived from this Recommendation may implement only a subset of the optional features allowed herein, or may incorporate features not addressed by the Recommendation.

In order to establish a common framework within which the Agencies may develop standardized telecommand services, the CCSDS advocates adoption of a layered systems architecture. Within this approach, specific layers of service (including their operational protocol and data structuring techniques) may be selected for implementation according to mission requirements.

The current layered set of CCSDS telecommand Recommendations was developed to match the conventional free-flying mission environment, as characterized by the transmission of command data at relatively low uplink data rates to spacecraft of moderate complexity. The CCSDS is currently examining the extension of these Recommendations (perhaps by defining expanded protocols and data structures within some of the layers) to a more complex mission environment, including the transmission of multiple data types at very high data rates to space vehicles which include extensive onboard data networking capability.

This Recommendation for Telecommand Data Routing Service was developed within the layered architectural framework, and embraces the standard data structures and data communication procedures which may be used by conventional missions within the intermediate telecommand system layers.

Through the process of normal evolution, it is expected that expansion, deletion or modification to this document may occur. This Recommendation is therefore subject to CCSDS document management and change control procedures which are defined in Reference [1].

DOCUMENT CONTROL

Document	Title	Date	Status/Remarks
CCSDS 202.0-B-1	Recommendation for Space Data System Standards. Telecommand, Part 2: Data Routing Service, Architectural Specification, Issue 1	January 1987	Original Issue

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REFERENCES

[1] "Procedures Manual for the Consultative Committee for Space Data Systems", Issue 1, Consultative Committee for Space Data Systems, August 1985 or later issue.

[2] "Telecommand, Summary of Concept and Service", CCSDS 200.0-G-6, Issue 6, Green Book, Consultative Committee for Space Data Systems, January 1987 or later issue.

[3] "Telecommand, Part 3: Data Management Service, Architectural Definition", Recommendation CCSDS 203.0-B-1, Issue 1, Blue Book, Consultative Committee for Space Data Systems, January 1987 or later issue.

[4] "Telecommand, Part 1: Channel Service, Architectural Specification", Recommendation CCSDS 201.0-B-1, Blue Book, Issue 1, Consultative Committee for Space Data Systems, January 1987 or later issue.

[5] "Packet Telemetry", Recommendation CCSDS 102.0-B-2, Issue 2, Blue Book, Consultative Committee for Space Data Systems, January 1987 or later issue.

[6] "Telemetry Channel Coding", Recommendation CCSDS 101.0-B-2, Issue 2, Blue Book, Consultative Committee for Space Data Systems, January 1987 or later issue.

[7] "Telecommand, Part 2.1: Command Operation Procedures, Detailed Specifications and State Matrices", CCSDS 202.1-R-3, Issue 3, Red Book, Consultative Committee for Space Data Systems, March 1987 or later issue.

The latest issues of CCSDS documents may be obtained from the CCSDS Secretariat at the address indicated on page i.

1 INTRODUCTION

1.1 PURPOSE AND SCOPE

The purpose of this document is to establish a common Recommendation for the implementation of a spacecraft telecommand "Data Routing Service" by the Agencies participating in the Consultative Committee for Space Data Systems (CCSDS). The operating principles and procedures for the CCSDS are defined in Reference [1]. The context of the Data Routing Service within the overall Telecommand System is described in Reference [2].

This Recommendation addresses the procedures and data unit formats implemented within the the Segmentation layer and the Transfer layer of the telecommand Data Routing Service.

1.2 APPLICABILITY

This Recommendation serves as a guideline for the development of compatible internal Agency standards in the field of spacecraft commanding. This Recommendation is not retroactive, nor does it commit any Agency to implement the recommended telecommand concepts at any future time. Nevertheless, all CCSDS Agencies accept the principle that all future implementations of telecommand which are used in cross-support situations will be based on this Recommendation.

The CCSDS has developed a layered concept for future spacecraft telecommanding, which is summarized in Reference [2]. Standard services are defined within each layer, and Agencies will be encouraged to develop corresponding facilities to provide these services in support of Projects.

To be fully compatible with the CCSDS concept, a Project's telecommanding architecture should follow this Recommendation for Data Routing Service, plus the Recommendations for telecommand "Data Management Service" and telecommand "Channel Service", which are described in References [3] and [4]. Projects may also elect to be partially compatible with the concept by interfacing with the standard systems at intermediate layers within any of the service specifications.

Where preferred options or mandatory capabilities are clearly indicated herein, the indicated sections of the specification must be implemented when this Recommendation is used as a basis for cross-support. Where optional subsets or capabilities are allowed or implied in this specification, implementation of these options or subsets is subject to specific bilateral cross-support agreements between the Agencies involved.

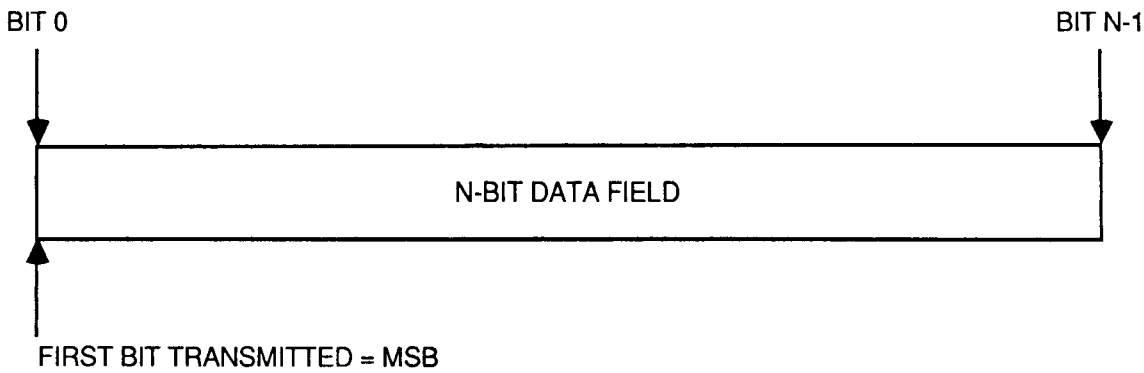
The recommendations in this document are to be invoked through the normal standards programs of each member Agency, and are applicable to those missions for which cross-support based on capabilities described in these recommendations is anticipated.

No later than five years from its date of issue, this Recommendation should be reviewed by the CCSDS Agencies to determine whether it should: 1) remain in effect without change; 2) be changed to reflect the impact of new technologies, new requirements, or new directions; or 3) be retired or cancelled.

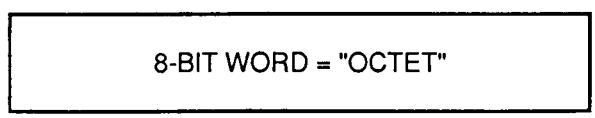
1.3 BIT NUMBERING CONVENTION AND NOMENCLATURE

In this document, the following convention is used to identify each bit in an N-bit field:

The first bit in the field to be transmitted (i.e., the most left justified when drawing a figure) is defined to be "Bit 0"; the following bit is defined to be "Bit 1" and so on up to "Bit N-1". When the field is used to express a binary value (such as a counter), the Most Significant Bit (MSB) shall be the first transmitted bit of the field, i.e., "Bit 0".



In accordance with modern data communications practice, spacecraft data fields are often grouped into 8-bit "words" which conform to the above convention. Throughout this Recommendation, the following nomenclature is used to describe this grouping:



By CCSDS convention, all "spare" bits shall be permanently set to value "zero".

Note that throughout this document, the word "Telecommand" may be abbreviated as "TC".

2 TELECOMMAND DATA ROUTING SERVICE OVERVIEW

A complete summary of the acronyms and terminology used internal to this document is presented in Annex A. A detailed specification of the services provided by each layer is presented in Annex B. The first-time reader should digest these Annexes before proceeding further in this document.

Figure 2-1 illustrates the significance of the Telecommand (TC) Data Routing Service in the overall Telecommand System, which contains three principal service elements: Telecommand Data Management Service; Telecommand Data Routing Service; and Telecommand Channel Service. Each service is documented in its own Recommendation. A more thorough discussion of the layered services, including expansion of Figure 2-1 in greater detail, is contained in Reference [2]. The Telecommand System is related to the Telemetry System as documented in Reference [5] and Reference [6].

The TC Data Routing Service enables user telecommand data units associated with higher layers to be reliably transferred to the spacecraft, drawing upon the Channel Service to perform its functions. The Data Routing Service contains two distinct layers of data handling operations:

(1) A **SEGMENTATION** layer, which prepares the user data units for transfer by breaking them into suitable-sized routable pieces, and permitting these pieces to be multiplexed together for transmission through the command channel.

(2) A **TRANSFER** layer, which encapsulates the routable pieces of user data into transfer data structures and controls their transmission through the channel, including the retransmission of any piece received in error.

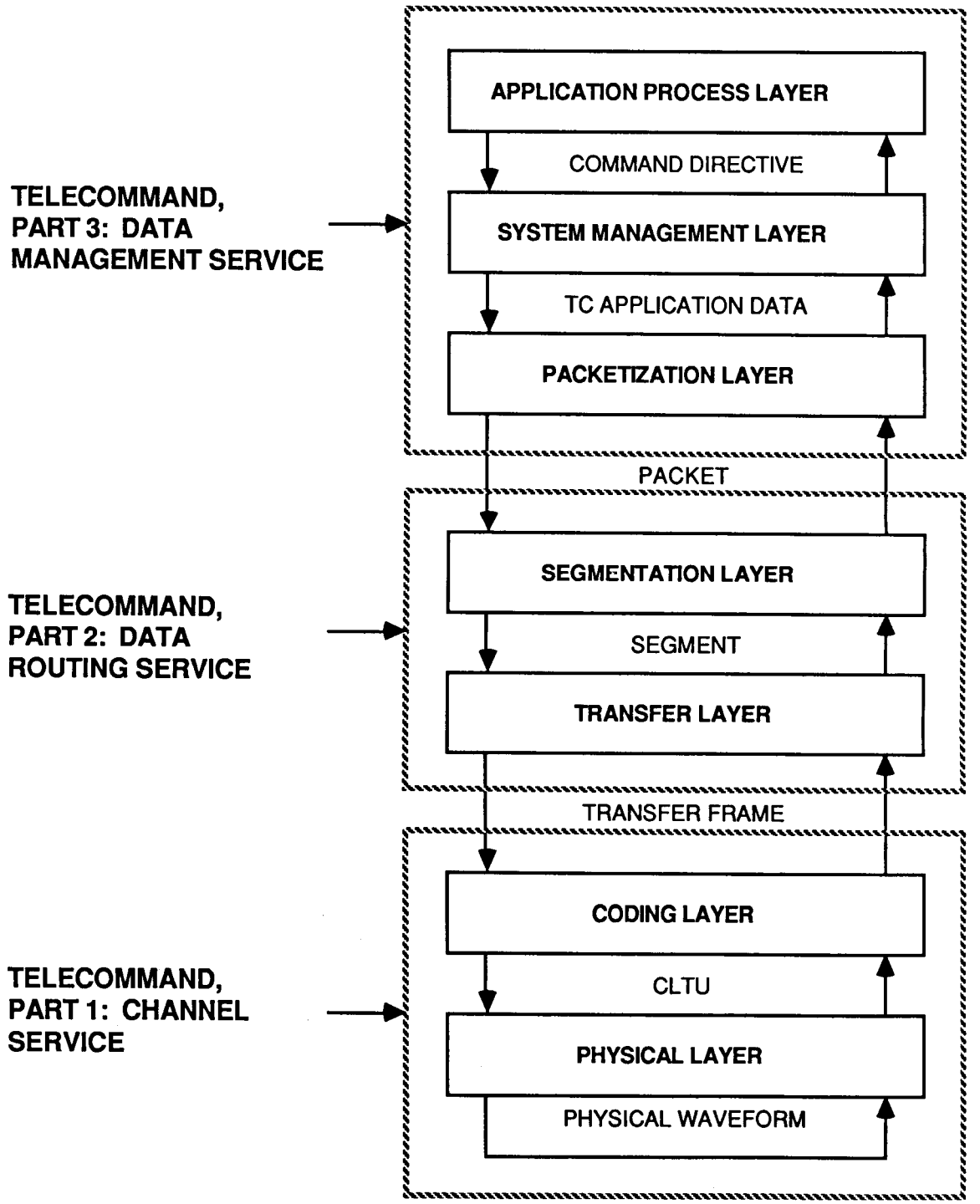


Figure 2-1: Telecommand System

The Data Routing Service provides an interface between the high-layer "user" elements of the TC System and the low layer communications channel through which data flow.

Because the underlying Channel Service inherently includes a noisy signal path, there is a finite probability that it will introduce an error. Since any error in the user's data will render them invalid, it is desirable to break large user data units into relatively small pieces (which will thus each have a lower probability of being invalidated by transmission error than if the entire user data unit were sent contiguously). This improves system throughput efficiency since only small pieces have to be retransmitted when errors are detected.

The Segmentation and Transfer layers provide the service of breaking large units of user data into smaller, routable pieces and moving them through the channel.

NOTE A: Figure 2-1 represents a logical view of the TC System, and physical implementations may not necessarily correspond to the sequential flow of operations implied by the figure.

NOTE B: This Recommendation primarily specifies the data structures and protocols flowing ACROSS the layers of the TC System, since these have a direct impact on the long lead-time design of future spacecraft hardware and software. Comprehensive definition of the associated flow of control instructions, which are required to initialize the layers and to direct the flow of TC data units BETWEEN the layers, remains an item for potential future extension of this document.

NOTE C: Inter-Agency cross-support gateways for telecommanding are discussed in Reference [2].

3 SEGMENTATION LAYER: STANDARD DATA STRUCTURES AND PROCEDURES

3.1 OVERVIEW OF THE LAYER

The TC Segmentation layer insulates variable-length TC user data units (e.g., TC Packets) in the layer above from the transmission processes in the layers below as follows:

(1) It breaks the user data units into pieces which are compatible with insertion into the protocol data unit of the layer below, i.e., the TC Transfer Frame data field.

(2) It enables different user data units to be multiplexed together so that they may share the transmission capacity of one Virtual Channel.

To accomplish service (2), the Segmentation layer provides "Multiplexer Access Points" (MAPs). A user data unit (e.g., a TC Packet) arriving at the input to the Segmentation layer is connected to an available MAP at the sending end of the layer, broken into appropriately sized pieces (TC Segments) if necessary, and is transferred to the corresponding MAP at the receiving end of the layer using the transfer service of the layers below. The layers below may provide one "real" physical channel, or may logically divide the real channel into multiple named "Virtual Channels". Each of "m" (m = 1 to 64) Virtual Channels (VCs) may have "n" (n = 1 to 64) distinct MAPs associated with it. The orientation of the Segmentation layer is shown in Figure 3-1.

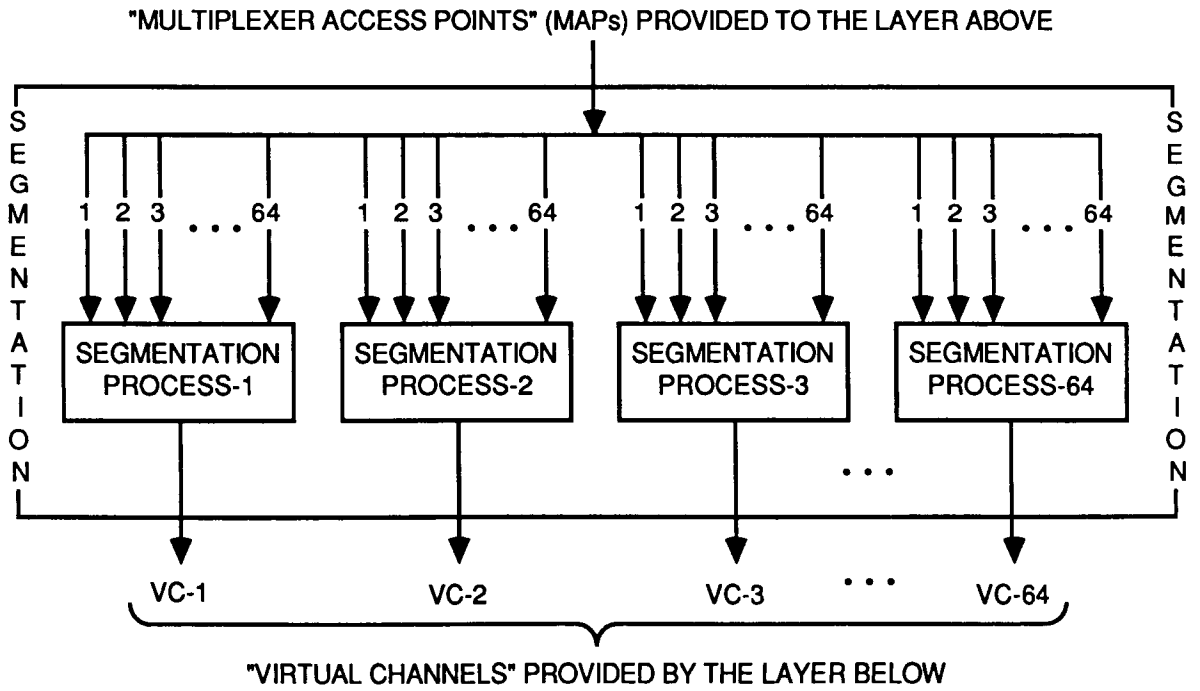


Figure 3-1: Orientation of the Segmentation Layer

For those missions which conform to the protocol of the layer below the Segmentation layer (i.e., the Transfer layer), it is possible to obtain the basic services of the lower layer providing that the length of the user data units does not exceed the maximum length of the TC Transfer Frame data field. In this case the Segmentation layer may be null and can therefore be bypassed.

Section 3.2 defines the format of the protocol data unit (the TC Segment), which is implemented within the Segmentation layer. Section 3.3 describes the procedures used within the Segmentation layer to break the user data units into TC Segments and reassemble them at the receiving end. It should be noted that the Segmentation layer does not include a telemetry reporting mechanism, since it relies on closed-loop procedures performed within the layer below.

3.2 STANDARD DATA STRUCTURES WITHIN THE LAYER

The TC Segment is used to encapsulate a complete user data unit (e.g., TC Packet) from the layer above, or portions of a user data unit if its length exceeds the maximum Segment length, during transfer to the spacecraft by the layer below. The TC Segment may be used to encapsulate high-level user data units which do not conform to the TC Packet protocol. The maximum length of the TC Segment depends on whether the optional TC Frame Error Control field is present. The TC Segment contains the following fields:

FIELD	LENGTH (OCTETS)	
	WITHOUT FRAME ERROR CONTROL	WITH FRAME ERROR CONTROL
SEGMENT HEADER SEQUENCE FLAGS (2 BITS) MAP ID (6 BITS)	1	1
SEGMENT DATA FIELD	250 (MAX)	248 (MAX)
TOTAL LENGTH	251 (MAX)	249 (MAX)

The format of the TC Segment is shown in Figure 3-2.

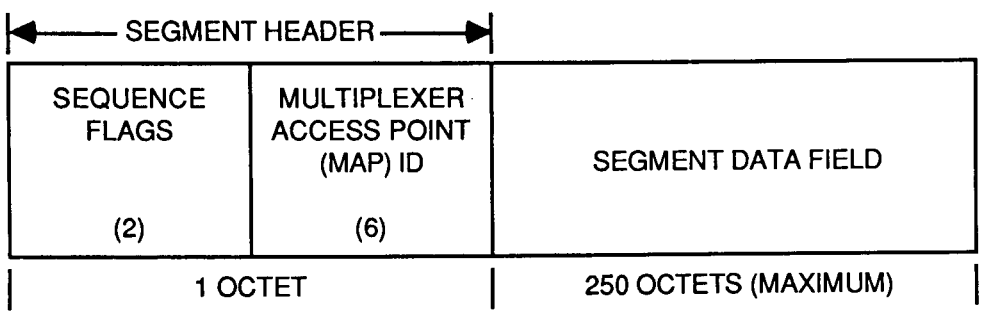


Figure 3-2: Telecommand Segment Format

3.2.1 SEGMENT HEADER

The Segment Header must always be present or always be absent (if the layer is bypassed) for a particular spacecraft and on a particular Virtual Channel, BUT NOT MIXED. It contains the following two fields:

(1) Sequence Flags (Bits 0,1)

This two bit field delimits the higher layer user data unit by indicating the sequential position of the Segment relative to the user data unit (e.g., TC Packet) of which the Segment is a part. The flags are interpreted as follows:

Bit 0	Bit 1	Interpretation
0	1	First Segment of user data unit on one MAP
0	0	Continuing Segment of user data unit on one MAP
1	0	Last Segment of user data unit on one MAP
1	1	Unsegmented user data unit

(2) Multiplexer Access Point (MAP) Identifier (Bits 2 through 7)

The MAP facility is a flow control mechanism which allows different types of user command data to be multiplexed together so that they share the communications capacity of one Virtual Channel, thus preventing any one user from monopolizing the data transmission resource.

This six-bit field enables up to 64 MAP addresses to be associated with each Virtual Channel provided by the layer below. Different user data units (e.g., separate TC Packets) arriving at the input to the Segmentation layer may each be either pre-assigned to their own MAP or may be dynamically assigned internal to the layer. Certain MAPs may have higher transmission priorities than others. The Segmentation layer breaks each user data unit on each MAP into pieces (Segments) which are compatible with insertion into the protocol data unit of the layer below, and multiplexes the Segments from up to 64 MAPs onto one Virtual Channel in accordance with user's delivery priorities and instructions.

If multiplexing is not performed within the Segmentation layer, but the Segment Header is otherwise required to be present, Bits 2 through 7 shall be set to a constant value for all TC Segments which are placed on that Virtual Channel.

3.2.2 SEGMENT DATA FIELD

The Segment Data Field contains all or a portion of the higher layer user data unit (e.g., TC Packet) which is to be transferred to the spacecraft. When the layer below is implemented using TC Transfer Frames, the length of the Segment Data Field depends on whether the frame

includes its optional Frame Error Control octets: if it does, the maximum length of the Segment Data Field is 248 octets; if not, it may be up to 250 octets long.

3.3 STANDARD PROCEDURES WITHIN THE LAYER

Figure 3-3 illustrates the process of segmenting a set of user data units (in this example a set of TC Packets) and inserting them as TC Segments into the data fields of TC Transfer Frames. The procedures for segmentation are as follows.

3.3.1 SENDING END SEGMENT PROCEDURES

The sending end of the TC Segmentation layer performs the following processing steps:

(1) Allocates the user data unit to a particular Multiplexer Access Point, according to its transfer priority. The allocation may be pre-specified by the layer above, or may be performed within the Segmentation layer.

(2) If the user data unit (e.g., the TC Packet) exceeds a predetermined length, the Segmentation layer divides it into portions that are compatible with insertion into the protocol data unit of the layer below (e.g., the TC Transfer Frame), and attaches a Segment Header to each portion. If the user data unit is a TC Packet, the first octet of the TC Packet Primary Header shall appear in the leading octet of first corresponding Segment Data Field. The first and continuing Segments may each have a length equal to the maximum length of the data field of the TC Frame. The last Segment shall have a length equal to the residue of the user data unit.

(3) Multiplexes together the TC Segments from one group of up to 64 MAPs onto one Virtual Channel, according to the mission's priority scheme, and passes the multiplexed stream to the layer below.

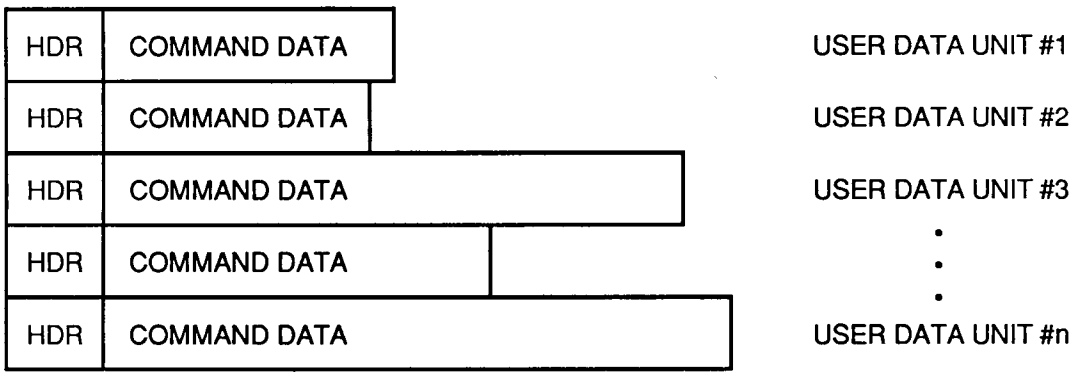
C A U T I O N

A TC SEGMENT SHALL NEVER CROSS A BOUNDARY BETWEEN USER DATA UNITS, I.E., IT SHALL ONLY CONTAIN:

(a) A PORTION OF ONE USER DATA UNIT, or

(b) ONE COMPLETE USER DATA UNIT.

Example: A set of user data units, each with length greater than the TC frame data field, assigned to one MAP and to be multiplexed together onto one Virtual Channel provided by the layer below:



The above queue of user data units is segmented into TC Transfer Frame data fields:

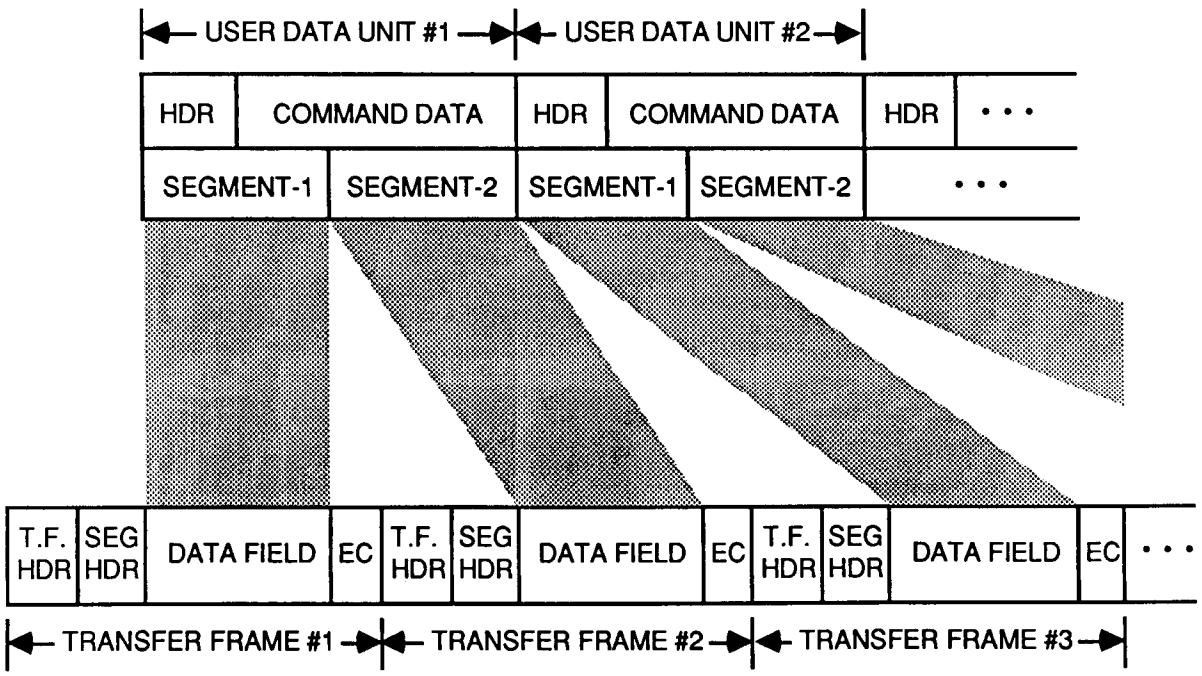


Figure 3-3: Example of the Segmentation Procedure

The Segmentation layer does not need any knowledge of Virtual Channel status from the layer below, other than an indication that the channel is available to accept data. However, the layer above may instruct the Segmentation layer to assign certain user data units to a particular pre-assigned Virtual Channel, and to request initialization of this Virtual Channel by the layer below.

3.3.2 RECEIVING END SEGMENTATION PROCEDURES

The receiving end of the TC Segmentation layer performs the following processing steps:

(1) Accepts a stream of multiplexed TC Segments on one Virtual Channel from the layer below (i.e., Transfer layer).

(2) Sorts these Segments according to the MAP IDs which appear in their Segment Headers.

(3) Reassembles the Segments (less headers) for each MAP, using the SEQUENCE FLAGS, in order to recreate the original user data unit.

(4) Passes the resulting user data unit to the layer above.

If the Segment Header has been omitted, then the processing steps at the receiving end are necessarily null, i.e., the layer below will deliver complete user data units directly to the layer above.

4 TRANSFER LAYER: STANDARD DATA STRUCTURES AND PROCEDURES

4.1 OVERVIEW OF THE LAYER

The TC Transfer layer is the "heart" of the standard TC System. It is this layer which takes care of most of the operations required to reliably move sets of user TC data from the sending end of the system to the receiving end in space.

Section 4.2 defines the format of the two standard data structures that reside within the layer: the "TC Transfer Frame", which flows from the sending end of the TC System to its receiving end, and the "Command Link Control Word" (CLCW), which is formatted by the receiving end and is transmitted back to the sending end via corresponding layers within the Telemetry System.

Section 4.3 defines a set of standard procedures which are associated with the layer: principal amongst these are the "Command Operation Procedures" (COPs) which control the transfer of data units from one end of the layer to the other, plus their respective "Frame Validation Checks" and "Frame Acceptance Checks".

Three COPs are defined in this Recommendation: COP-0, COP-1 and COP-2. Each COP consists of a pair of synchronized procedures which execute within one Virtual Channel (VC) at the sending and receiving ends of the layer. At the sending end a "Frame Operation Procedure" (FOP) is executed. At the receiving end a corresponding spacecraft "Frame Acceptance and Reporting Mechanism" (FARM) is activated.

The orientation of these elements within the Transfer layer is shown in Figure 4-1.

4.2 STANDARD DATA STRUCTURES WITHIN THE LAYER

This section describes the formats of the following two standard protocol data units which reside within the TC Transfer layer:

(1) The TC Transfer Frame, which is the data structure that is "uplinked" to the receiving end of the layer on the spacecraft.

(2) The TC Command Link Control Word (CLCW), which is the data structure that is "downlinked" by the spacecraft (inserted in the Trailers of standard Telemetry Transfer Frames) back to the sending end of the layer in order to provide reports which describe the status of acceptance and reassembly of TC Frames.

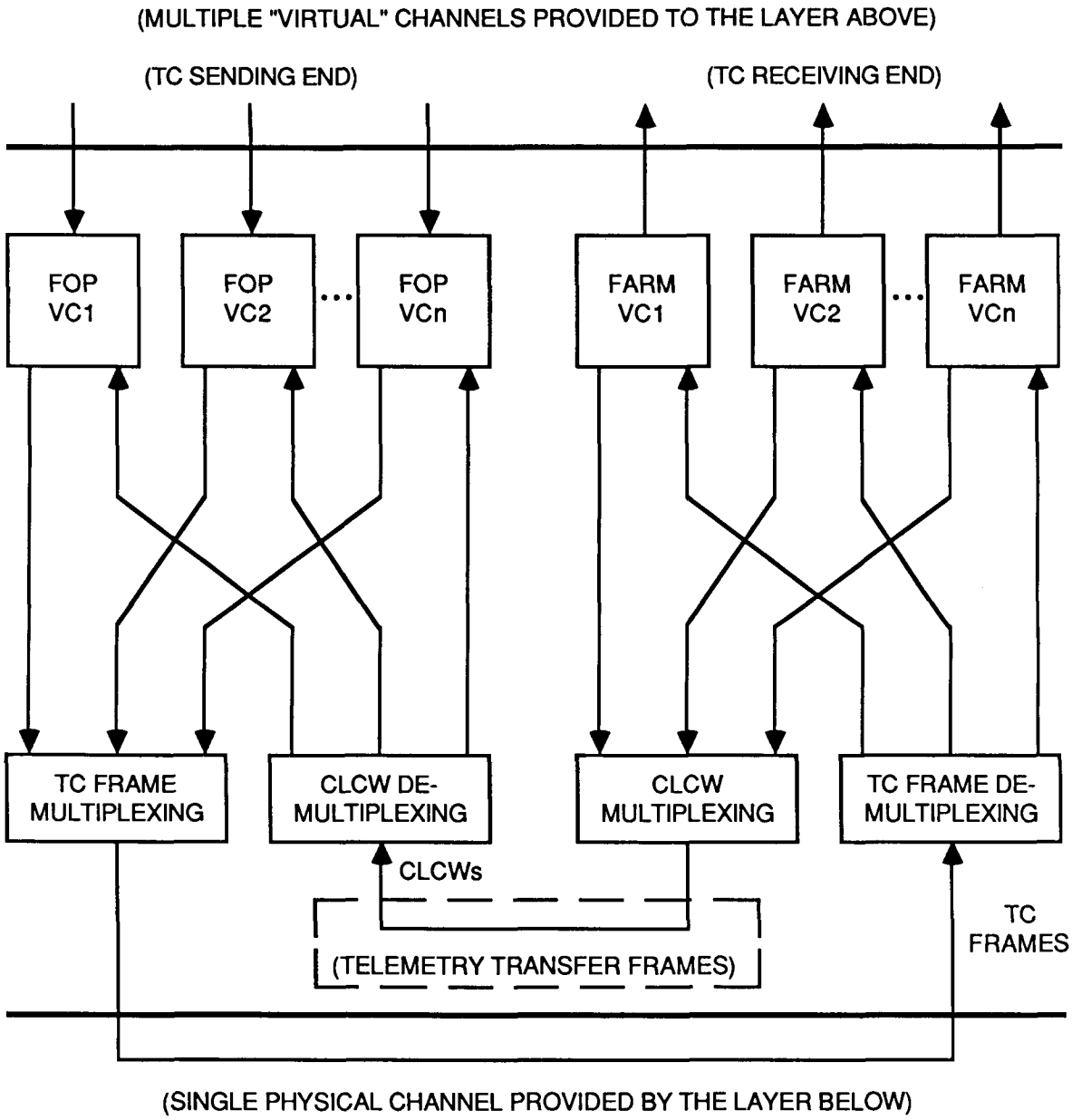


Figure 4-1: Orientation of the Transfer Layer

4.2.1 TC TRANSFER FRAME FORMAT

The TC Frame (Figure 4-2) contains the following major fields:

Major Field	Length (Octets)
FRAME HEADER	5
FRAME DATA FIELD	Variable (up to 251)
FRAME ERROR CONTROL (Optional)	(2)
	---
	256 octets (maximum)

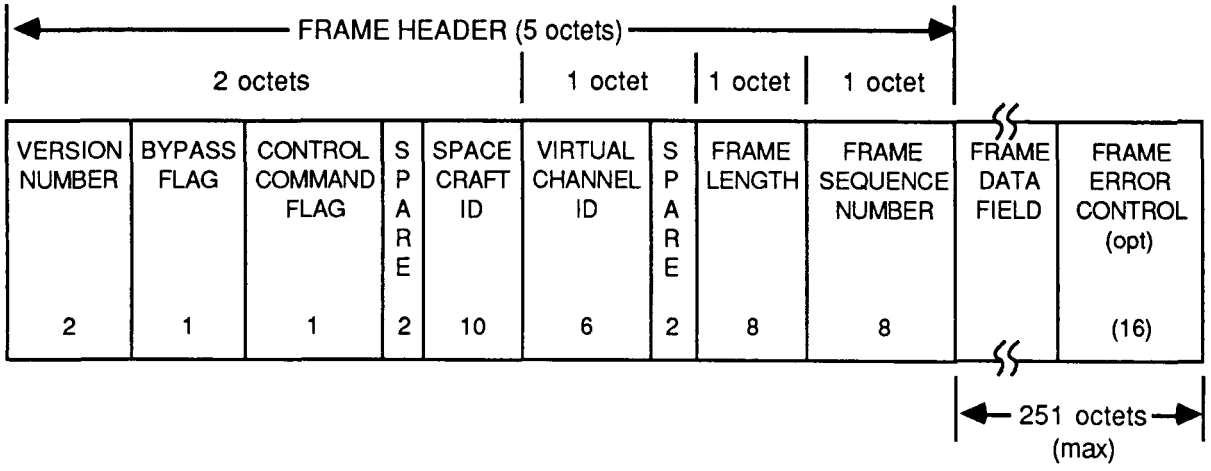


Figure 4-2: TC Transfer Frame Format

4.2.1.1 Transfer Frame Header. The FRAME HEADER of the TC Transfer Frame consists of the following fields, grouped into octets as shown:

Field	#Bits	#Octets
Version Number	2	
Bypass Flag	1	
Control Command Flag	1	
Reserved Spares	2	
Spacecraft ID	10	2
Virtual Channel ID	6	
Reserved Spares	2	1
Frame Length	8	1
Frame Sequence Number	8	1
		—
		5 octets

The first two octets of the FRAME HEADER contain the following field allocations:

(1) VERSION NUMBER (Bits 0,1)

The VERSION NUMBER occupies the two most significant bits of the Frame Header. Future changes in the TC Transfer Frame structure may be accommodated by changing the VERSION NUMBER. At present, only Version "1" of the TC Transfer Frame (the format specified herein) is defined. It shall be identified by setting Bits 0,1 to value "0,0".

(2) BYPASS FLAG (Bit 2)

The single bit BYPASS FLAG controls the application of "Frame Acceptance Checks" by the receiving spacecraft. ALL Frames received by the spacecraft first undergo a basic standard set of "Frame Validation Checks", which are applied regardless of the setting of the BYPASS FLAG. If the BYPASS FLAG is not set, each Frame is subsequently tested against the additional Frame Acceptance Checks, which vary according to the "Command Operation Procedure" (COP) that has been selected to transfer the TC Frames across the layer (see Section 4.3).

The Frame Acceptance and Reporting Mechanism (FARM) associated with each COP (i.e., COP-0, COP-1 or COP-2) can be made to operate in a normal "Acceptance" (frame "Type-A") mode or a "Bypass" (frame "Type-B") mode, according to the setting of the Bit 2 BYPASS FLAG.

Setting Bit 2 to value "0" specifies a Type-A TC Frame: acceptance of this Type of frame by the spacecraft shall be subject to the normal Frame Acceptance Checks of the governing FARM (i.e., for COP-0 this is FARM-0A; for COP-1 this is FARM-1A; and for COP-2 this is FARM-2A).

Setting Bit 2 to value "1" specifies a Type-B TC Frame: the normal Frame Acceptance Checks of the governing FARM shall be bypassed (i.e., FARM-0B, FARM-1B or FARM-2B).

Necessarily, it must be possible to interleave Type-A and Type-B TC Frames in order to conduct some operations.

(3) CONTROL COMMAND FLAG (Bit 3)

The CONTROL COMMAND FLAG specifies whether the data field of the TC Transfer Frame is conveying transfer **"Control** Commands" (the **"C"** mode), or **"Data"** (the **"D"** mode).

In the "C" mode the first octet(s) of the Frame Data Field contain control information which sets the parameters of the receiving end of the Transfer layer to the proper configuration to accept telecommand data.

In the "D" mode the Frame Data Field contains the user data unit from the layer above (e.g., a TC Packet or a TC Segment).

Setting Bit 3 to value "0" indicates the "D" mode to the receiving spacecraft, i.e., that the Frame Data Field contains data.

Setting Bit 3 to value "1" indicates the "C" mode to the receiving spacecraft, i.e., that the Frame Data Field contains Control Commands. The combined states of the BYPASS FLAG and the CONTROL COMMAND FLAG are interpreted by the receiving spacecraft as shown in Table 4-1.

Table 4-1: Interpretation of the "Bypass" and "Control Command" Flags

Bypass Flag	Control Command Flag	Interpretation
0	0	Frame Data Field carries TC data (e.g., Packets or Segments), subject to Acceptance Check under control of FARM-0AD/-1AD/-2AD.
0	1	Reserved for future application.
1	0	Frame Data Field carries TC data (e.g., Packets or Segments), with all Frame Acceptance Checks bypassed under control of FARM-0BD/-1BD/-2BD.
1	1	Frame Data Field carries Transfer layer setup Control Commands, with all Frame Acceptance Checks bypassed under control of FARM-0BC/-1BC/-2BC.

(4) RESERVED SPARES (Bits 4,5)

These two bits are reserved for future application. At present, Bits 4,5 shall be set to value "0,0".

(5) SPACECRAFT IDENTIFIER (Bits 6 through 15)

These ten bits carry the identification code for the spacecraft being commanded. The Secretariat of the CCSDS assigns the SPACECRAFT IDENTIFIER to each vehicle within a particular mission as defined in Reference [1].

The third octet of the FRAME HEADER contains the following field allocations:

(6) VIRTUAL CHANNEL IDENTIFIER (Bits 0 through 5)

As described in Section 3, the Transfer layer provides a "Virtual Channel" service to the layer above. Beneath the Transfer layer is the single physical telecommand data channel which is provided by the Channel Service (Reference [4]). The Virtual Channel facility allows this single physical channel to be logically multiplexed, on a frame-by-frame basis, so that its transmission capacity may be shared.

Every TC Transfer Frame shall have a 6-bit VIRTUAL CHANNEL ID field present in the Frame Header. Each state of the identifier creates one Virtual Channel, so that up to 64 different logical paths may be defined through the single physical channel. The Transfer layer may therefore present up to 64 Virtual Channels to the layer above.

If the layer above is the Segmentation layer, then each Virtual Channel may also have up to 64 Multiplexer Access Points (MAP's) attached to it for the purpose of multiplexing user data units together.

NOTE

If multiplexing is not performed in the Segmentation layer (i.e., if only one MAP is activated per Virtual Channel, or if the Segment Header is omitted for a particular mission), then the Virtual Channel feature of the Transfer layer provides an alternative method for multiplexing user data onto the physical channel. Using this feature of the Transfer layer, up to 64 concurrent user data units may be multiplexed together by attaching each to its own dedicated Virtual Channel during transfer through the physical channel. However, since every open Virtual Channel has its own CLCW reporting scheme, Virtual Channel multiplexing may increase the spacecraft reporting complexity.

The internal partitioning and use of the Virtual Channel field is mission-specified, e.g., some of the bits may be allocated by a mission to form a "Spacecraft Sub-ID", which allows different spacecraft data handling chains to be addressed.

(7) RESERVED SPARES (Bits 6,7)

These two bits are reserved for future application. At present, Bits 6,7 shall be set to value "0,0".

The fourth octet of the FRAME HEADER contains the following field:

(8) FRAME LENGTH (Bits 0 through 7)

This 8-bit field contains a sequential count "C" which equals one less than the total octets in the TC Transfer Frame. The count is measured from the first bit of the FRAME HEADER to the last bit of the FRAME ERROR CONTROL FIELD (if present), or the last bit of the FRAME DATA FIELD if the error control is omitted. The size of this field limits the maximum length of a TC Transfer Frame to 256 octets. The length count "C" is expressed as:

"C" = (Total Number of Octets) - 1

The fifth octet of the FRAME HEADER contains the following field:

(9) FRAME SEQUENCE NUMBER (Bits 0 through 7)

The FRAME SEQUENCE NUMBER, which within this Recommendation is denoted as N(S), is an upcounting binary number which is assigned to each TC Frame by the TC Transfer layer, and which remains a viable entity only within this layer.

The FRAME SEQUENCE NUMBER enables the FARM to check the sequentiality of incoming Type-A TC Frames. The 8-bit FRAME SEQUENCE NUMBER field supports a modulo 256 sequence count.

The FRAME SEQUENCE NUMBER is Virtual Channel dependent, i.e., the Transfer layer shall maintain a separate FRAME SEQUENCE NUMBER for each of the (up to 64) VIRTUAL CHANNELS.

Note that COP-0 never uses this field, and COP-1 and COP-2 do not use this field when operating with **Type-B** TC Frames: in these cases the contents of the FRAME SEQUENCE NUMBER field shall be set to **"all zeros"**.

4.2.1.2 Transfer Frame Data Field. The FRAME DATA FIELD, which is of variable length up to a maximum of 251 octets (249 octets if the FRAME ERROR CONTROL FIELD is present), shall contain either an integral number of octets of telecommand data corresponding to one "TC User Data Unit" supplied by the layer above or an integral number of octets of "Control Command" information.

When the layer above conforms to the CCSDS Telecommand architecture, a TC User Data Unit will take the form of one TC Packet or one TC Segment. If the layer above does not conform to the CCSDS Telecommand architecture, the TC User Data Unit may be any other higher layer user data structure if desired.

Control Commands are data structures which are generated and used only within the Transfer layer: they are used to specify to the spacecraft the governing FARM parameters for the VIRTUAL CHANNEL to which they are addressed.

A TC FRAME WHICH CARRIES A CONTROL COMMAND IN ITS DATA FIELD SHALL NOT ALSO CARRY A TC USER DATA UNIT.

If the TC Frame is identified (by the CONTROL COMMAND FLAG in the Frame Header) as containing a Control Command in its Data Field, the control information is conveyed by means of the fields which are shown in Figure 4-3: these fields are CONTROL SPECIFIER and CONTROL QUALIFIER.

The Control Command format is self-extending. The CONTROL SPECIFIER field contains a flag which indicates if the CONTROL QUALIFIER field is present. The CONTROL QUALIFIER field contains a flag which indicates if another CONTROL QUALIFIER follows. The CONTROL QUALIFIERS may therefore be chained together as required to construct complex Control Command structures, i.e., several control functions may be concatenated within a single TC Frame.

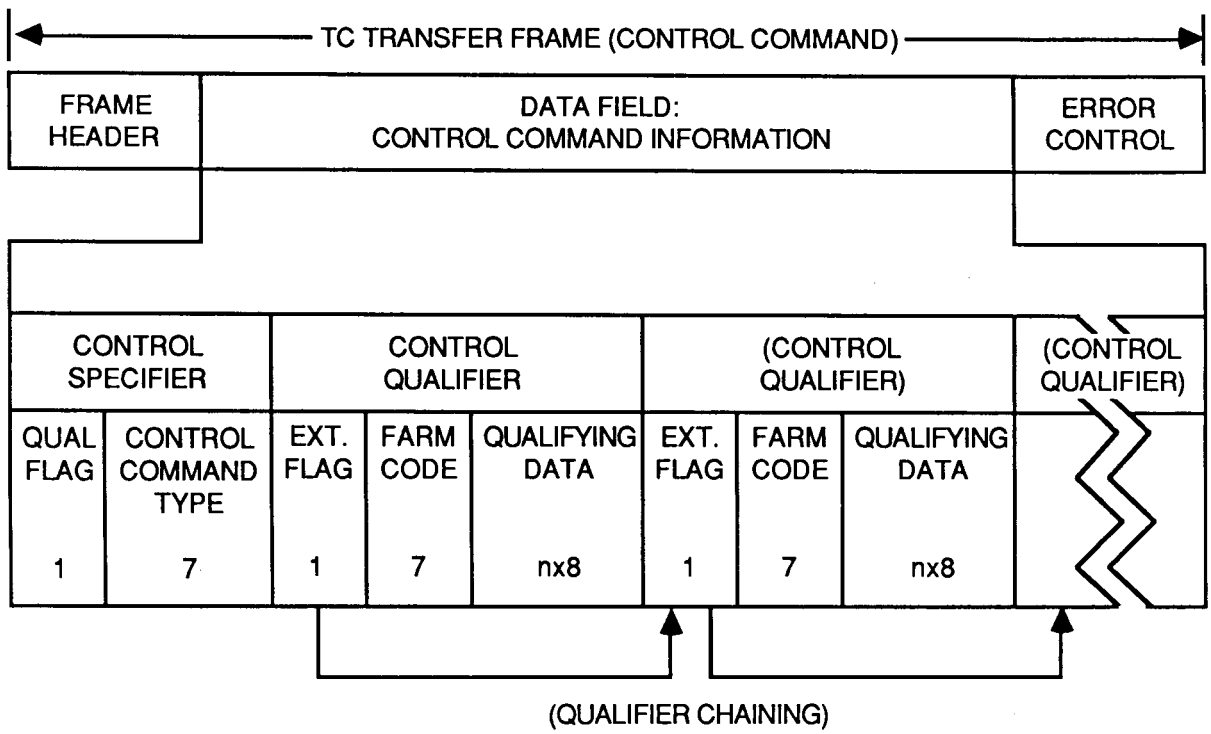


Figure 4-3: Control Command Format

(1) CONTROL SPECIFIER (8 bits)

The CONTROL SPECIFIER field, which must be present in every Control Command, contains the following two subfields:

(a) Qualifier Flag (Bit 0)

This flag is used to indicate if the CONTROL SPECIFIER field is followed by a CONTROL QUALIFIER field.

If Bit 0 is set to value "0", this indicates that there is no CONTROL QUALIFIER field, i.e., the Control Command consists only of the one-octet CONTROL SPECIFIER field.

If Bit 0 is set to value "1", this indicates there is at least one CONTROL QUALIFIER field present, following the CONTROL SPECIFIER.

(b) Control Command Type (Bits 1 through 7)

These seven bits are formatted as a list which defines the type of control action (receiving spacecraft FARM setup procedure) that the Control Command is effecting for a particular Virtual Channel. The selected Virtual Channel is addressed via the VIRTUAL CHANNEL ID field in the Frame Header. Most (but not all) control actions require that a CONTROL QUALIFIER field is present in order to fully specify the desired FARM configuration. The assignment of bits for the eight presently defined CONTROL COMMAND TYPEs is as follows:

Bit 1 — Bit 7	**CONTROL COMMAND TYPE Interpretation**
0000000	"UNLOCK"
0000001	"OPEN"
0000010	"MODIFY"
0000011	"SUSPEND"
0000100	"RESUME"
0000101	"CLOSE"
0000110	"DUMP VIRTUAL CHANNEL STATUS"
0000111	"SET NEXT EXPECTED FRAME SEQUENCE NUMBER TO ZERO"
0001000 through 1111111	Reserved for future application

NOTE A: Not all COPs use every Control Command: a full specification of the applicability of these commands to each COP is contained in Reference [7].

NOTE B: A Virtual Channel may be left permanently OPEN for the duration of a mission, in which case the OPEN, SUSPEND, RESUME and CLOSE Control Commands are not applicable to that Channel.

(i) CONTROL COMMAND TYPE-0, "UNLOCK"

The UNLOCK Control Command specifier is used to "unlock" the spacecraft Frame Acceptance and Reporting Mechanism (FARM).

The FARM has a built-in safety mechanism which will go into "Lockout" whenever it detects a received Type-A TC Frame which violates certain pre-programmed Frame Acceptance Checks, and will refuse to accept further Type-A frames until unlocked by this Control Command. When an UNLOCK is received, the buffers containing the Frame which caused the LOCKOUT shall be cleared. The exact conditions for entering Lockout within each COP are described in Section 4.3.

There is no CONTROL QUALIFIER field required for the UNLOCK Control Command. Necessarily, it MUST be transmitted to the spacecraft as a Type-B TC Frame, so that the Frame Acceptance Checks are bypassed.

(ii) CONTROL COMMAND TYPE-1, "OPEN"

The OPEN Control Command specifier is used to activate a particular spacecraft VIRTUAL CHANNEL in preparation for fresh data transfer through that channel, according to the logical rules of the selected COP.

The OPEN specifier is normally followed by one or more CONTROL QUALIFIER fields which establish the FARM setup parameters to be used during the transfer. An OPEN command clears the FARM buffers for a specified Virtual Channel and starts telemetry reporting of the status of that Virtual Channel, via the Command Link Control Word (CLCW) in the Telemetry Transfer Frame. Unless the OPEN command contains a specification to the contrary, a freshly OPENed Virtual Channel shall always expect to receive a first Type-A TC Frame bearing a FRAME SEQUENCE NUMBER N(S) set to value "00000000".

(iii) CONTROL COMMAND TYPE-2, "MODIFY"

The MODIFY Control Command specifier is used to change the FARM parameters of a spacecraft Virtual Channel which has previously been OPENED. It must be followed by one or more CONTROL QUALIFIER fields.

(iv) CONTROL COMMAND TYPE-3, "SUSPEND"

The SUSPEND Control Command specifier is used to place an OPENed Virtual Channel into an inactive state without CLOSING it. This may be used to freeze the transmission of TC Frames through one particular Virtual Channel while transmission resources are temporarily devoted to another higher priority Virtual Channel.

The SUSPEND command is not normally followed by a CONTROL QUALIFIER field. A SUSPENDed Virtual Channel may be reactivated (with all of its previous setup parameters, reports and previously accepted TC Frames intact) by transmitting a RESUME Control Command, addressed to that Virtual Channel. While SUSPENDed, a Virtual Channel enters the LOCKOUT state, but its FARM buffers are not cleared when a RESUME command is sent.

While SUSPENDed, CLCW reporting for that Virtual Channel is reduced to a lower priority: the FARM shall periodically format one or more "reminder" CLCWs which report its status to the sending end. **Immediately following receipt of a SUSPEND command, the FARM shall format at least three CLCWs, with normal reporting priority, so that the new status of this Virtual Channel can be confirmed before the reporting priority is lowered.**

(v) CONTROL COMMAND TYPE-4, "RESUME"

The RESUME Control Command specifier re-activates a previously SUSPENDed Virtual Channel, with all of its operational parameters unchanged. It is not normally accompanied by a CONTROL QUALIFIER field. The RESUME command resets the LOCKOUT condition induced by a SUSPEND, but without clearing any FARM buffers.

(vi) CONTROL COMMAND TYPE-5, "CLOSE"

The CLOSE Control Command specifier is used to deactivate a previously OPENed spacecraft Virtual Channel after data transfer through it is completed, and to stop telemetry reporting of its status. It

is not normally accompanied by a CONTROL QUALIFIER field. A CLOSEd channel is dormant and is ready for future use via an OPEN command. **When a Virtual Channel CLOSEs, at least three CLCWs shall be formatted by the FARM (with normal reporting priority) so that the FOP may confirm proper operation prior to the termination of reporting for that Virtual Channel.**

(vii) CONTROL COMMAND TYPE-6, "DUMP VIRTUAL CHANNEL STATUS"

The DUMP VIRTUAL CHANNEL STATUS Control Command specifier is used to initiate a complete cycle of CLCW reports from ALL Virtual Channels which are available on a spacecraft, regardless of their OPEN, SUSPEND or CLOSE status. This command is normally reserved for use as a diagnostic tool.

(viii) CONTROL COMMAND TYPE-7, "SET NEXT EXPECTED FRAME SEQUENCE NUMBER TO ZERO"

The SET NEXT EXPECTED FRAME SEQUENCE NUMBER TO ZERO Control Command is used to program V(R), the "NEXT EXPECTED FRAME SEQUENCE NUMBER" counter which is maintained by the FARM, to the value "all zeros". It does not require a CONTROL QUALIFIER field. Necessarily, a separate V(R) counter shall be maintained by the FARM for each Virtual Channel.

All other entries on the CONTROL COMMAND TYPE list formed by Bits 1 through 7 are reserved by CCSDS for future application.

(2) CONTROL QUALIFIER (m-octets)

The specific FARM setup parameters associated with an OPEN or MODIFY Control Command are contained in the CONTROL QUALIFIER field. Presence or absence of the CONTROL QUALIFIER field is indicated by the QUALIFIER FLAG in the CONTROL SPECIFIER field.

The leading octet of the CONTROL QUALIFIER field contains a "FARM CODE" which identifies the FARM function that is to be changed. The trailing octet(s) of the CONTROL QUALIFIER field contain the "QUALIFYING DATA", which supply the parameters that are to be programmed in association with that FARM CODE.

(a) Extension Flag (Bit 0)

This flag is used to indicate if another CONTROL QUALIFIER field follows this one.

If Bit 0 is set to value "0", this indicates that there is no subsequent CONTROL QUALIFIER field, i.e., this is the only field present.

If Bit 0 is set to value "1", this indicates that another CONTROL QUALIFIER field follows immediately after the QUALIFYING DATA subfield of this CONTROL QUALIFIER. This feature permits multiple CONTROL QUALIFIERS to be chained together within the context of a single TC Frame containing an OPEN or MODIFY Control Command specifier.

(b) FARM Code (Bits 1 through 7)

These seven bits are formatted as a list containing a FARM CODE which selects the FARM function that is to be changed for a particular Virtual Channel. The operational setup parameters for the selected FARM function are supplied within the QUALIFYING DATA FIELD; therefore each FARM CODE is followed by one or more octets of QUALIFYING DATA. The assignment of the FARM CODES is as follows:

Bit 1 — Bit 7	**FARM CODE Interpretation**
0 0 0 0 0 0 0	Set NEXT EXPECTED FRAME SEQUENCE NUMBER
0 0 0 0 0 0 1	Set width of MISSING FRAME WINDOW
0 0 0 0 0 1 0	Set width of FARM SLIDING WINDOW
0 0 0 0 0 1 1	Set Negative Edge of FARM SLIDING WINDOW
0 0 0 0 1 0 0	Set width of FARM FIXED WINDOW
0 0 0 0 1 0 1	Set COMMAND OPERATION PROCEDURE
0 0 0 0 1 1 0 t h r o u g h 1 1 1 1 1 1 1	Reserved for future application

(i) FARM CODE-0, set NEXT EXPECTED FRAME SEQUENCE NUMBER

The FARM CODE-0 Control Command is used to program V(R), the "NEXT EXPECTED FRAME SEQUENCE NUMBER", into FARM-1 or FARM-2 only.

When operating in the Type-A TC Frame (Acceptance Check) mode of COP-1 and COP-2, the FARM tracks the FRAME SEQUENCE

NUMBER N(S) of incoming frames and maintains a count "V(R)" of the next-expected number. The actions taken by the FARM if N(S) within a received frame does not match V(R) are COP-dependent, and are described in Section 4.3.

This Control Command allows V(R) to be preset to any desired value at the beginning of a command load using the OPEN feature (or at intermediate points using the MODIFY feature) to match the FRAME SEQUENCE NUMBER N(S) of the next Type-A TC Frame which will be transmitted.

The value of the new V(R) is contained in one octet of QUALIFYING DATA, which immediately follows this FARM CODE. Necessarily, a separate V(R) shall be maintained for each Virtual Channel.

(ii) FARM CODE-1, set MISSING FRAME WINDOW

The FARM CODE-1 Control Command is used in conjunction with the OPEN or MODIFY feature to set the width of a "MISSING FRAME WINDOW" into FARM-2 only. Procedures for using this window are defined in Section 4.3.

The value of the new MISSING FRAME WINDOW is contained in one octet of QUALIFYING DATA, which immediately follows this FARM CODE.

(iii) FARM CODE-2, set FARM SLIDING WINDOW

The FARM CODE-2 Control Command is used in conjunction with the OPEN or MODIFY feature to set the width of a "FARM SLIDING WINDOW" into FARM-1 and FARM-2 only. Procedures for using this window are described in Section 4.3.

The new value "K" of the FARM SLIDING WINDOW is contained in one octet of QUALIFYING DATA, which immediately follows this FARM CODE.

(iv) FARM CODE-3, set FARM SLIDING WINDOW NEGATIVE EDGE

The FARM CODE-3 Control Command is used in conjunction with the OPEN or MODIFY feature to set a "FARM SLIDING WINDOW NEGATIVE EDGE" into FARM-1 and FARM-2 only. Procedures for using this window are described in Section 4.3.

The new value of the FARM SLIDING WINDOW NEGATIVE EDGE is contained in one octet of QUALIFYING DATA, which immediately follows this FARM CODE.

(v) FARM CODE-4, set FARM FIXED WINDOW

The FARM CODE-4 Control Command is used in conjunction with the OPEN or MODIFY feature to set the width of a "FARM FIXED WINDOW" into FARM-0, 1 or 2. Procedures for using this window are described in Section 4.3.

The new value of the FARM FIXED WINDOW is contained in two octets of QUALIFYING DATA, which immediately follow this FARM CODE.

(vi) FARM CODE-5, set COMMAND OPERATION PROCEDURE

The FARM CODE-5 Control Command is used in conjunction with the OPEN or MODIFY feature to set the spacecraft FARM on a particular Virtual Channel to match the overall COP which is in use. The three legal COP specifications are contained in one octet of QUALIFYING DATA, which immediately follows this FARM CODE. This QUALIFYING DATA octet is formatted as follows:

Bit 0	**Bit 7**	**Interpretation**
0 0 0 0 0 0 0 0		Select FARM-0 for COP-0 operation
0 0 0 0 0 0 0 1		Select FARM-1 for COP-1 operation
0 0 0 0 0 0 1 0		Select FARM-2 for COP-2 operation
0 0 0 0 0 0 1 1		
through		Reserved for future application
1 1 1 1 1 1 1 1		

(c) Qualifying Data (n-octets)

The QUALIFYING DATA subfields contain the data values which are required to support the actions specified by each of the FARM CODES.

An example of a complex Control Command with its qualifying data is shown in Figure 4-4.

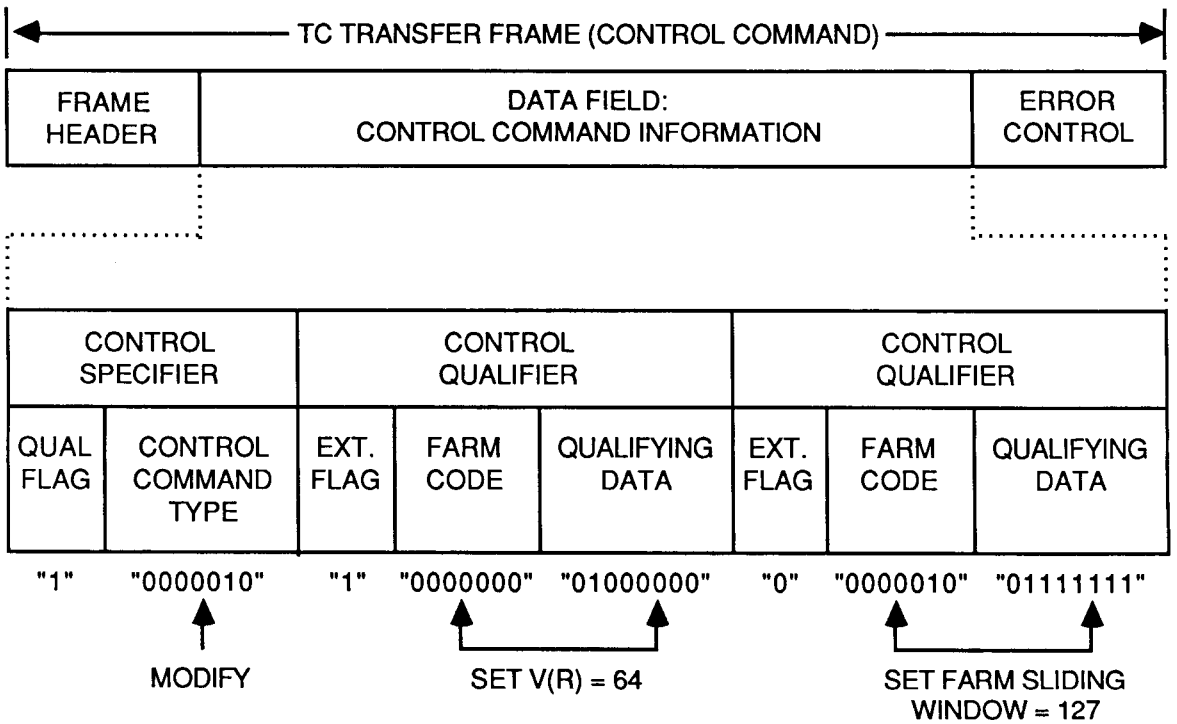


Figure 4-4: Example of a Control Command

4.2.1.3 Transfer Frame Error Control Field. The purpose of this optional 16-bit field (which occupies the two trailing octets of the TC Frame) is to provide a capability within the Transfer layer for detecting possible errors that may have been introduced into the frame during lower-layer data handling processes, and that remained undetected within those layers.

Error control in the Transfer layer is required only to the extent necessary to meet the following overall minimum TC System requirements:

(1) The TC Transfer Frame rejection rate shall be better than 1 frame rejected per 10^3 frames that are transmitted.

(2) The undetected TC Transfer Frame error rate shall be better than 1 frame in error per 10^9 frames that are transmitted.

Coding schemes within the Channel Service layers contribute to this performance specification: in many cases these schemes alone will satisfy the requirements. However, if additional protection is required in the Transfer layer to meet this minimum (or a more stringent) mission performance requirement, use of the following cyclic redundancy code is recommended:

(a) The generator polynomial is:

$$g(x) = x^{16} + x^{12} + x^5 + 1$$

(b) Both encoder and decoder are initialized to the "all ones" state for each TC Transfer Frame.

(c) Parity ("P") generation is performed over a data space "D", where "D" includes the TC Frame Header and Data Field as shown in Figure 4-5.

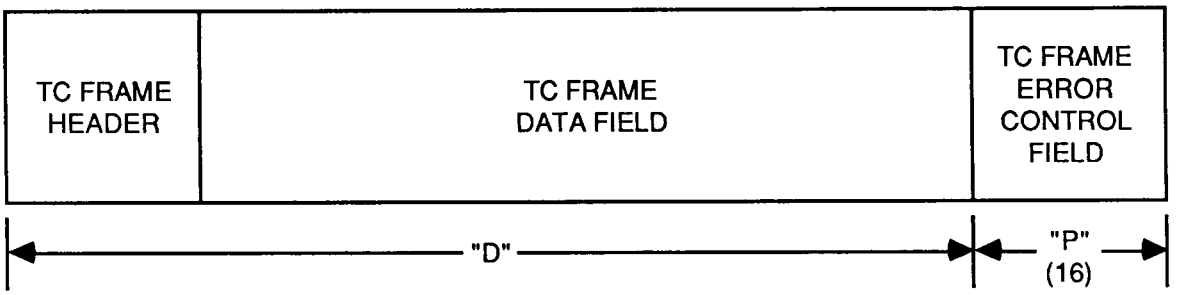


Figure 4-5: Frame Error Control Generation

A more detailed description of the recommended encoding/decoding procedure is contained in Reference [2].

NOTE

As described in Reference [2], when concatenated with the lower-layer Channel Service coding scheme that is described in Reference [4], the Transfer layer polynomial specified above will provide a probability of undetected frame error of better than 1×10^{-14}.

4.2.2 COMMAND LINK CONTROL WORD (CLCW) FORMAT

The CLCW, which is a four-octet word that is conveyed once per CCSDS Telemetry Transfer Frame (Reference [5]), provides the mechanism by which the FARM reports back the status of frame acceptance to the Frame Operation Procedure (FOP) at the sending end of the Transfer layer. The information conveyed by the CLCW varies slightly according to the selected COP (of which the FOP and the FARM are components).

NOTE

THE CONTROLLING SPECIFICATION FOR HOW THE CLCW IS USED WITHIN EACH COP IS CONTAINED IN REFERENCE [7].

The CLCW is the only reporting mechanism for the TC Transfer layer. Although it is not necessary that the Telemetry reporting rate match the Telecommand transfer rate, some minimum CLCW sampling rate is necessary for the proper operation of all of the COPs. CLCW reporting priorities, which must be established wherever the efficient operation of a COP is limited by the telemetry capacity, are specified in Reference [7].

The format of the CLCW is shown in Figure 4-6.

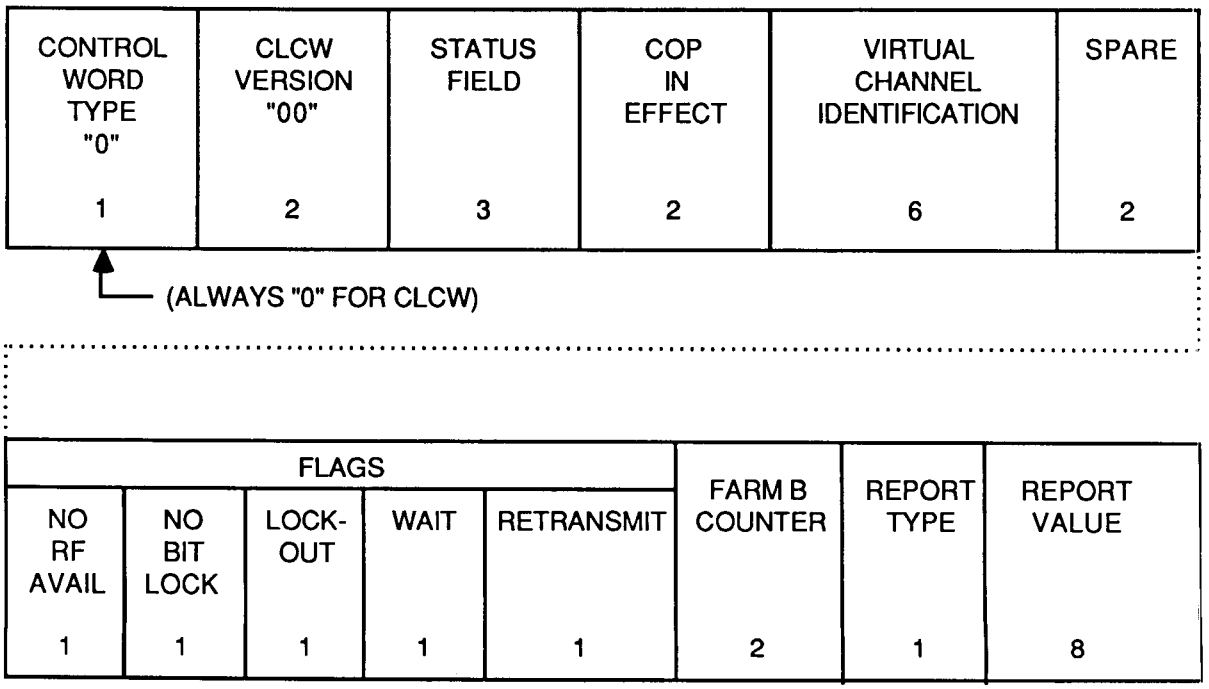


Figure 4-6: Command Link Control Word Format

The CLCW contains the following fields:

Field		Length (Bits)
CONTROL WORD TYPE		1
CLCW VERSION		2
STATUS FIELD		3
COP IN EFFECT		2
VIRTUAL CHANNEL ID		6
RESERVED SPARE		2
FLAGS:		5
- No rf available	(1)	
- No bit lock	(1)	
- Lockout	(1)	
- Wait	(1)	
- Retransmit	(1)	
FARM B COUNTER		2
REPORT TYPE		1
REPORT VALUE		8
		32 bits (4 octets)

Unless otherwise stated, all fields are required elements of protocol for all COPs.

(1) CONTROL WORD TYPE (Bit 0)

This one bit field shall always be set to zero to indicate that this is a CLCW in the Telemetry Transfer Frame. (Note: this field in the Telemetry frame may be allocated for other purposes when not supporting telecommand operations, Reference [5]).

(2) CLCW VERSION NUMBER (Bits 1,2)

The two bit CLCW VERSION NUMBER field is included to provide future growth flexibility. However, at present a single "Version-1" CLCW format meets the reporting requirements of the three COPs as defined in this Recommendation: it shall be indicated by setting Bits 1,2 to value "0,0". The format of the Version-1 CLCW report is described herein.

(3) STATUS FIELD (Bits 3,4,5)

Application of this field is mission-specified. It can be used, for example, to provide the three LSBs of a FARM-maintained "Session Counter", i.e., the count of the number of Virtual Channels which automatically CLOSE themselves and stop reporting when a pre-specified set and number of TC Transfer Frames has been accepted by the FARM on that Virtual Channel.

This field may be used by Agencies or Centers for local enhancements to TC operations and is not part of the basic COP protocol.

(4) COP IN EFFECT (Bits 6,7)

These two bits indicate the COP which has been selected at the receiving end via a Control Command sent to the FARM. The characteristics of each COP are discussed in Section 4.3. Note that different COPs may run on different Virtual Channels. Bits 6,7 are interpreted as follows:

Bit 6	**Bit 7**	**Interpretation**
0	0	COP-0
0	1	COP-1
1	0	COP-2
1	1	Reserved

(5) VIRTUAL CHANNEL ID (Bits 8-13)

This field defines the VIRTUAL CHANNEL with which this report is associated. Each Virtual Channel which is OPEN shall have its own CLCW reporting activated. The field shall contain "all zeroes" if the Virtual Channel concept is not being used within the transmitted TC Frames.

(6) RESERVED SPARES (Bits 14,15)

These two bits are reserved by CCSDS for future application. For the present, Bits 14,15 shall be set to value "0,0".

(7) FLAGS (Bits 16,17,18,19,20)

(a) NO RF AVAILABLE flag (Bit 16)

The NO RF AVAILABLE flag provides a logical indication of the "ready" status of the radio frequency (rf) elements within the physical data channel provided by the layer below (i.e., the Channel Service). Precise definition of the set of physical states which must each be in the "ready" condition before commanding is possible is mission-specified. For example, the flag can represent a logical sum of the overall ready status of components such as the rf transponder and the demodulator.

Whenever Bit 16 is set to value "0", the physical channel is AVAILABLE (i.e., any TC Transfer Frame will be received and processed by the Channel Service layers and passed on to the Transfer layer if correct).

Whenever Bit 16 is set to value "1", the physical channel is NOT AVAILABLE and TC Transfer Frames cannot be transferred without corrective action within the Channel Service layers. The exact nature of any corrective action required when this flag is set is specified in Reference [7].

The single NO RF AVAILABLE flag applies to all Virtual Channels. This input parameter to the CLCW is updated whenever a change is signalled by the layer below.

(b) NO BIT LOCK flag (Bit 17)

The NO BIT LOCK flag is an optional, mission-specific engineering measurement which provides a performance quality indicator that indicates specifically whether the layer below is working normally by having enough signal energy to achieve bit synchronization with the received data stream. If bit lock is not achieved, this may indicate that the layer below is operating at a non-nominal performance level and that the TC Frame rejection rate may be correspondingly abnormally high.

When Bit 17 is used and set to value "0", this indicates BIT LOCK ACHIEVED. When Bit 17 is used and set to value "1", this indicates NO BIT LOCK ACHIEVED.

This flag is not part of the basic COP protocol, and may therefore be used by Agencies or Centers for local enhancements to TC operations. If not used, it shall be set permanently to value "0".

The single NO BIT LOCK flag applies to all Virtual Channels. This input parameter to the CLCW is updated whenever a change is signalled by the layer below.

(c) LOCKOUT flag (Bit 18)

Bit 18 is set to value "1" to indicate LOCKOUT whenever a Type-A TC Frame is received on a particular Virtual Channel which violates certain FARM-specific validation or acceptance checks. Once the FARM is in LOCKOUT, all subsequent Type-A TC Frames are rejected until the condition is cleared. The conditions for entering and exiting LOCKOUT for each COP are described in Section 4.3 and are specified in Reference [7]. If the FARM is not in LOCKOUT, Bit 18 shall be set to value "0".

Necessarily, separate LOCKOUT flags shall be maintained for each Virtual Channel when using COP-1 or COP-2: however, COP-0 only uses a single LOCKOUT flag for all Virtual Channels.

(d) WAIT flag (Bit 19)

When Bit 19 is set to value "1", this indicates that the receiving end of the Transfer layer is unable to pass data to the higher layers on a particular Virtual Channel. This may be caused by temporary lack of storage and/or processing resources in the receiving end of the Transfer or higher layers.

When Bit 19 is set to value "1" (i.e., WAIT) for a particular Virtual Channel, all further Type-A TC Frames on that channel shall be rejected by the FARM until the condition is cleared by freeing the congestion, either automatically or by taking appropriate control action as defined in Reference [7].

When Bit 19 is set to value "0" (i.e., DON'T WAIT), normal Type-A commanding may proceed on that channel.

The WAIT flag is not used by all COPs: the precise specifications for its use are contained in Reference [7]. Necessarily, separate WAIT flags shall be maintained for each Virtual Channel.

(e) RETRANSMIT Flag (Bit 20)

The RETRANSMIT flag facility speeds the operation of all COPs by providing immediate indication (Bit 20 set to value "1") to the FOP at the sending end that one or more Type-A frames on a particular Virtual Channel has been rejected or found missing by the FARM and therefore a retransmission period must be scheduled. The conditions which cause the flag to be set are different for each COP: they are described in Section 4.3 and are specified in Reference [7].

When Bit 20 is set to value "0" this indicates that there are no outstanding Type-A frame rejections in the sequence received so far, and thus retransmissions are not required. Necessarily, separate RETRANSMIT flags shall be maintained for each Virtual Channel.

(8) FARM-B COUNTER (Bits 21,22)

This field contains the two least significant bits of a FARM-B COUNTER. This counter is maintained within the FARM and increments once each time a Type-B TC Transfer Frame is accepted in BYPASS mode (i.e., FARM-0BC/D, FARM-1BC/D or FARM-2BC/D) on a particular Virtual Channel. The field supports the verification by the FOP that BYPASS mode frames (Control or user Data) were accepted by the spacecraft, since these commands are not subject to acceptance checks and therefore do not change the state of the counters contained within the REPORT VALUE field.

Necessarily, separate FARM-B COUNTERs shall be maintained for each Virtual Channel.

(9) REPORT TYPE (Bit 23)

This field, which is only applicable to COP-2 operations, contains a flag that specifies the type of information contained within the REPORT VALUE field. The REPORT TYPE flag must be interpreted in conjunction with the value of the COP IN EFFECT field (Bits 6,7) in the CLCW.

When operating in COP-0 or COP-1 (CLCW Bits 6,7 are set to values "0,0" or "0,1"), Bit 23 is ignored.

When operating in COP-2 (CLCW Bits 6,7 are set to value "1,0"), Bit 23 is interpreted as follows:

Bit 23 State	Contents of "REPORT VALUE" Field
"0"	N(R) = OBSERVED VALUE OF THE NEXT EXPECTED FRAME SEQUENCE NUMBER, V(R)
"1"	M(R) = MISSING FRAME SEQUENCE NUMBER

The definitions of N(R), V(R), M(R) are explained in more detail in Reference [2].

Necessarily, separate REPORT TYPE flags shall be maintained for each Virtual Channel when operating COP-2. The reporting priority of each Virtual Channel within COP-2 is mission-specified.

(10) REPORT VALUE (Bits 24-31)

This field, which shall always be one octet long, contains the value of certain counters which are required for the operation of each COP.

For COP-0 the REPORT VALUE field shall ALWAYS contain a "FARM-A COUNTER", which shall increment once each time a FARM-0AD TC Frame is accepted on a particular Virtual Channel. The FARM-A COUNTER shall NOT increment when a FARM-0BC or FARM-0BD frame is accepted; however, in those cases the FARM-B COUNTER shall increment.

For COP-1 the REPORT VALUE field shall ALWAYS contain "N(R)", i.e., the current observed value of the FARM's NEXT EXPECTED FRAME SEQUENCE NUMBER V(R). The FARM V(R) counter shall increment once each time a FARM-1AD TC Frame is accepted on a particular Virtual Channel. The V(R) counter shall NOT change when a FARM-1BC or FARM-1BD frame is accepted; however, in those cases the FARM-B COUNTER shall increment.

For COP-2 the REPORT VALUE field shall (according to the value of the REPORT TYPE flag) either contain N(R), i.e., the current observed value of V(R), the FARM's NEXT EXPECTED FRAME SEQUENCE NUMBER (which is maintained similar to COP-1), or it shall contain "M(R)", i.e., the "MISSING FRAME SEQUENCE NUMBER". An M(R) report contains the FRAME SEQUENCE NUMBER N(S) of a frame which was detected by FARM-2 to be missing in the received sequence, and which must therefore be retransmitted. Missing frames are detected when FARM-2 observes discontinuities in the N(S) upcounting sequence as each frame is accepted within the various windows that are in effect.

The CLCW reports of N(R) and M(R) for COP-2 shall be multiplexed into Telemetry Transfer Frames. Within each Virtual Channel, the CLCW reporting

priority is that all M(R)s shall be transmitted first, beginning with the "oldest" missing frame, stepping through the list to the most "recent" M(R), and finally reporting V(R) before repeating this cycle.

In COP-2, the V(R) or the M(R) counters shall only be updated when FARM-2AD frames are accepted. These counters shall NOT change when a FARM-2BC or FARM-2BD frame is accepted; however, in those cases the FARM-B COUNTER shall increment.

Necessarily, separate FARM-A, V(R) or M(R) counters shall be maintained for each Virtual Channel.

Detailed specifications for the conditions under which each counter is incremented are contained in Reference [7].

4.3 STANDARD PROCEDURES WITHIN THE LAYER

Standard procedures within the Transfer layer are concerned with the following operations:

(1) At the receiving end of the system, reconstituting TC Frames from the data stream provided by the layer below, and removing any "fill" data inserted by that lower layer.

(2) At the receiving end of the system, performing standard "Frame Validation Checks" on all TC Frames reconstituted from the layer below.

(3) At both ends of the system, executing the Command Operation Procedure which is used to move TC Frames across the Transfer layer, including performing "Frame Acceptance Checks" and establishing and using various counters, numbers and windows.

4.3.1 FRAME DELIMITING AND FILL REMOVAL PROCEDURE

The Telecommand Channel Service (Reference [4]) resides immediately below the Transfer layer. At the sending end of the TC System, the Transfer layer passes one or more TC Frames to the Channel Service, which encodes the frames to protect them from errors which may be introduced as they are transmitted through the physical channel.

The receiving end of the Transfer layer receives as an input from the layer below a series of data octets, corresponding to the decoded frame(s), which have been declared "clean" by the layer below insofar as they contain no detected errors. The layer below provides a "Data Start" signal to the Transfer layer, indicating that data are being transferred.

The Data Start signal shall be set TRUE while the layer below is in the process of actively transferring data octets. Since the first octet transferred after Data Start goes TRUE corresponds to the first octet of the first TC Transfer Frame, the receiving end of the Transfer layer may delimit this frame -- and each of any successive TC Transfer Frames -- by reading the FRAME LENGTH field in the first header, and then successively reading the FRAME LENGTH field in each subsequent header.

The Data Start signal shall become FALSE (indicating "Data Stop") when the layer below encounters a decoding failure and octet transfer ceases. The decoding failure may be caused by the normal end of the transmitted TC Frame(s), or by a genuine channel-induced error.

If one or more valid FRAME LENGTH fields are detected by the receiving end of the Transfer layer and the number of octets received when the Data Stop condition occurs equals the number of octets specified by the FRAME LENGTH(s), then each Frame shall be passed on to the Frame Validation Check procedure (see 4.3.2) as it is delimited.

If a valid FRAME LENGTH field is detected by the receiving end of the Transfer layer but the number of octets received when the Data Stop condition occurs is less than the number of octets specified by that FRAME LENGTH, this entire Frame shall be discarded since this indicates that a decoding failure has occurred, probably due to a channel error detected during reception of the data stream within the layer below.

If normal decoding proceeds but the number of octets in the series of frames does not map exactly into the number of octets provided by the data space of the coding data structure provided the layer below (e.g., the TC Codeblock, Reference [4]), the layer below may send trailing octets of "Fill" data to the Transfer layer. If this happens, the number of octets transferred when Data Stop occurs will be greater than the number of octets specified by the FRAME LENGTH(s), and the Fill must be stripped by the Transfer layer.

The characteristics of the present TC Codeblock structure are such that no more than six octets of Fill can occur. If LESS THAN FIVE trailing octets of Fill are present, then they cannot possibly form a Frame Header, and they will be immediately discarded by the Transfer layer. If FIVE OR SIX trailing octets of Fill exist, the Transfer layer data handling process might attempt to interpret the Fill data as a new Transfer Frame Header: however, the subsequent Frame Validation Check (see 4.3.2) will prevent this from happening because the Fill pattern of "10101010" appearing in each octet will violate at least one of the validation tests; in particular, this pattern appearing where the FRAME LENGTH field might be expected will indicate a frame length that exceeds the number of octets received from the layer below, thus failing a test and causing the trailing five or six octets to be discarded.

4.3.2 "FRAME VALIDATION CHECK" CRITERIA

After each TC Transfer Frame is reconstituted from the string of octets provided by the layer below, it will next be subjected to a set of standard tests called a "Frame Validation Check". The Frame Validation Check shall be applied to ALL incoming TC Transfer Frames, regardless

of the COP in effect and regardless of whether they are Type-A or Type-B. Failure to pass any test within the Frame Validation Check shall cause the Transfer Frame to be rejected (discarded): within COP-0 only, the FARM shall also enter LOCKOUT. The Frame Validation Check consists of the following tests:

(1) The TC Frame must have an expected VERSION NUMBER.

(2) The TC Frame must have the expected SPACECRAFT ID.

(3) The TC Frame Header must not contain any states which are not consistent with the implemented features for that spacecraft.

(4) The value of the FRAME LENGTH must be consistent with the number of octets that are present.

(5) If implemented, the FRAME ERROR CONTROL test must pass.

(6) If implemented, the Data Field of a TC Frame containing a Control Command must be consistent with the allowable range of control parameters for that spacecraft.

4.3.3 COMMAND OPERATION PROCEDURE (COP)

The Command Operation Procedure which is selected for a mission fully specifies the closed-loop protocols executed by the sending and receiving ends of the Transfer layer of the TC System. The COP, which exists wholly within the Transfer layer, consists of a pair of synchronized procedures: a Frame Operation Procedure (FOP) that executes within the sending entity; and a Frame Acceptance and Reporting Mechanism (FARM) that executes within the receiving entity. The sending FOP transmits TC Frames to the receiving FARM. The FARM returns telemetered Command Link Control Words (CLCWs) to the FOP and thus closes the loop by providing reports of the status of frame acceptance.

The COP provides a basic Quality Of Service (QOS) within the Transfer layer that is central to the operation of the TC System, i.e., the delivery of data units to the receiving end of the layer above, correct and without omission or duplication, and in the same sequential order in which they were received from the layer above at the sending end.

Within this Recommendation, three specific COPs (COP-0, COP-1 and COP-2) are defined that all provide this common QOS. These three COPs are recursively related to each other, and they are numbered in order of increasing complexity of their FARMs.

NOTE

The selection of the specific COP to be used for a given mission is a complex decision based on many factors, including channel error characteristics, propagation delays and permissible mission complexity. Because of the many factors involved in choosing a COP, this Recommendation does not attempt be be judgmental or to suggest specific applications: it merely presents the available COPs and leaves the selection to the mission designer.

C A U T I O N

THE CONTROLLING SPECIFICATIONS FOR THE LOGICAL OPERATIONS WHICH MUST BE EXECUTED TO PERFORM COP-0, COP-1 AND COP-2 ARE CONTAINED IN A MORE DETAILED CCSDS RECOMMENDATION (REFERENCE [7]). IN THE EVENT OF ANY CONFLICT BETWEEN THE DESCRIPTIVE TEXT CONTAINED IN THIS ARCHITECTURAL SPECIFICATION AND THE TEXT OF REFERENCE [7], THE MORE DETAILED SPECIFICATIONS CONTAINED IN REFERENCE [7] SHALL PREVAIL.

Underlying the Transfer layer is the physical telecommand data channel which interconnects its sending and receiving ends. If a perfect data channel existed, the QOS would be assured since the exact duplicate of the series of data units which was input to the sending end would appear at the receiving end. However, space data channels are noisy and may introduce errors or discontinuities into transmitted data streams. The job of the COP within the Transfer layer is therefore to ensure the correctness, completeness and sequentiality of the delivered data units, in the presence of such errors or discontinuities introduced by the layer below.

Correctness of the delivered data units is guaranteed (within known error probabilities) by means of the error-protection encoding applied by the Channel Service, and by the Frame Validation Check performed by the Transfer layer. However, validation of the completeness, sequentiality and non-duplication of the delivered data units requires that a frame accounting (i.e., numbering) scheme is implemented in either the FOP or the FARM that comprises the COP.

If the frame accounting is performed by the FOP (for example, FOP-0, which inherently has knowledge of the intended sequentiality of the transmitted frames), an IMPLICIT numbering scheme may be implemented, i.e., the FRAME SEQUENCE COUNTER field is not used. The FOP keeps track of the integer number of frames which it has transmitted, monitors the initial telemetered value of an appropriate FARM counter which is implemented to increment once each time a frame is accepted, and maintains continuous knowledge of successive increments of this counter. Upon detection of an error (failure to pass the Frame Validation Check) the FARM enters LOCKOUT and will refuse to accept any subsequent Type-A frames until UNLOCKED by a Type-B control command. When LOCKOUT is observed, the FOP may "go-back-n" frames and resume transmission at the proper point in the sequence, where the value of "n" is calculated using the initial and current values of the FARM counter. Within

this process the FOP contains all of the intelligence to keep track of the order in which frames are accepted by the spacecraft, and to ensure that out-of-sequence acceptance does not occur. COP-0 uses this implicit numbering scheme. Other optional recovery strategies within COP-0 include retransmitting the entire sequence of frames when an error is detected (with the possibility of consequent frame duplication), or halting and alerting a higher-layer authority.

If the accounting is performed by the FARM, then the FARM must be supplied with the knowledge of intended sequentiality via an EXPLICIT numbering scheme. To accomplish this, each frame must be equipped with an upcounting absolute FRAME SEQUENCE COUNTER. The FARM then makes acceptance decisions based on this absolute number.

The simplest explicit FARM logic (for example, FARM-1) is that which only permits frames to be accepted if they are received bearing absolute FRAME SEQUENCE NUMBERS which are in the proper upcounting sequential order: upon detection of the first frame sequence error, the FARM will reject all subsequent frames which do not contain the expected FRAME SEQUENCE NUMBER, and the FOP must go-back-n and resume sequential retransmission by repeating all frames transmitted after the error occurred. Such FARM logic removes the need for onboard storage by requiring that the FOP controls this strict transmitted sequentiality of the received data units. COP-1 uses explicit numbering and simple FARM logic. FARM-1 has knowledge of sequentiality, but in order for its logical operations to be simple and to avoid the need for buffering and reordering frames prior to delivery to the layer above, it places a constraint on the FOP that it will only accept numbered TC Frames which are received in strict upcounting sequential order: no missing frames are permitted.

A more complex set of explicit FARM logic (for example, FARM-2) is that which allows all good received frames to be accepted (possibly out of sequence) and which reports missing frames in the sequence back to the FOP, which schedules their selective retransmission: this technique requires storage within the FARM to hold the incomplete sequence while waiting for the missing pieces. COP-2 uses this more complex FARM logic. While FOP-2 nominally transmits numbered TC Frames in upcounting sequential order, FARM-2 allows (within certain bounds) some frames to be received in non-sequential order, i.e., missing frames are permitted. FARM-2 must therefore buffer the frames while awaiting retransmission of missing items, and re-order them into the proper upcounting sequence prior to extraction of their data fields for delivery to the layer above.

Note that while the FARMs for the three COPs are recursively related, the FOPs may be significantly different since dissimilar retransmission strategies are used.

4.3.3.1 COP Counters, Numbers and Windows. Each specific COP may select from a menu of several common "counters", "numbers" and "windows" in order to perform its basic operation, or to enhance its reliability or utility: the counters and numbers are used to validate sequentiality, while the windows either act as safety devices to keep the FOP and FARM properly coordinated, or they provide value-added enhancements which increase the utility of the Transfer layer. Not all of the specific COPs use all of the counters, numbers or windows which are described below, but their definitions are consistent across all COPs.

(1) FRAME SEQUENCE NUMBER, N(S)

When explicit numbering techniques are used, each TC Frame is assigned a FRAME SEQUENCE NUMBER, called "N(S)", by the sending end of the Transfer layer. This number is inserted into the TC Frame Header. COP-0 does not use this number, though the field must be present in each frame and is set to value "all zeros". Within COP-1 and COP-2 the FRAME SEQUENCE NUMBER indicates the order in which the data units contained within Type-A frames are to be reassembled by the receiving end prior to delivery to the layer above. When a series of Type-A frames is first transmitted by the FOP, their FRAME SEQUENCE NUMBERS are arranged in strict upcounting sequential order. Type-B commands have sequence numbers (set to value "all zeros" by convention), but these are not used by the FARM and must not disturb the upcounting order of the Type-A's.

The FRAME SEQUENCE NUMBERS may be generated using two different methods:

(a) Method-A supports the pre-numbering (and possibly pre-encoding by layers below) of TC Frames. The FRAME SEQUENCE NUMBERS of a series of TC Frames are pre-assigned in upcounting sequence prior to passing them to the FOP for transmission. Within Method-A, the first TC Frame of the series may be a "SET NEXT EXPECTED FRAME SEQUENCE NUMBER" Control Command which presets the FARM V(R) counter to expect the N(S) of the first Type-A frame of the series. Care must be exercised to preserve Transfer layer sequentiality when using Method-A.

(b) Method-B supports the dynamic allocation of FRAME SEQUENCE NUMBERS by the FOP. Within Method-B, the FOP reads the N(R) reports received in telemetered CLCWs to determine the observed value of the FARM's NEXT EXPECTED FRAME SEQUENCE NUMBER, V(R). The FOP then dynamically numbers the upcoming series of Type-A frames sequentially relative to N(R), i.e., the first Type-A frame is assigned an N(S) = N(R), the second is assigned an N(S) = {N(R)+1}, etc. Necessarily, the channel encoding by layers below is also dynamic when using Method-B.

These two methods have been supplied to accommodate different ground network capabilities and philosophies. The "Set V(R)" capability is required if the ground network element which hosts the FOP does not support dynamic alteration of pre-prepared TC Frames. The selection of Method-A or Method-B is therefore dependent on the ground network support service which is provided.

(2) NEXT EXPECTED FRAME SEQUENCE NUMBER, V(R)

When explicit numbering techniques are used within COP-1 or COP-2, the FARM compares the N(S) in each incoming Type-A TC Frame with a FARM-maintained

NEXT EXPECTED FRAME SEQUENCE NUMBER, V(R), the value of which is one count more than the N(S) in the last accepted Type-A frame.

Within both COP-1 and COP-2, the current value of V(R) for each Virtual Channel is regularly reported to the FOP via the N(R) measurement in the REPORT VALUE field of the telemetered CLCW. The V(R) parameter is not applicable to COP-0, since COP-0 does not use frame sequence numbering.

For COP-1, the appearance of N(R) in the telemetered CLCW positively acknowledges to the FOP that the FARM has accepted ALL Type-A frames up to and including the frame bearing a FRAME SEQUENCE NUMBER N(S) which has a value of {N(R)-1}.

For COP-2, the appearance of N(R) in the telemetered CLCW positively acknowledges to the FOP that the highest-numbered Type-A frame that the FARM has accepted bears a FRAME SEQUENCE NUMBER N(S) which has a value of {N(R)-1}. However, in COP-2 there may be missing frames which have FRAME SEQUENCE NUMBERS lower than {N(R)-1}.

(3) MISSING FRAME SEQUENCE NUMBER, M(R)

In COP-2, which permits frames to be accepted out of sequence, a Type-A frame bearing an N(S) greater than V(R) will be accepted, provided its sequence number falls within certain window limits relative to V(R). When such a frame is accepted, V(R) is set to {N(S)+1} and all of the frame sequence numbers between and including the old V(R) and the new {N(S)-1} are declared to be missing.

Each one of the missing frames is identified by its MISSING FRAME SEQUENCE NUMBER, "M(R)". The list of M(R)s is cyclically reported back to the FOP in the REPORT VALUE field of the telemetered CLCW so that retransmission of the missing frames may be scheduled. When a retransmitted frame is accepted under COP-2 with an N(S) less than V(R), but matching one of the M(R)s on the missing frames list, the frame is accepted and the corresponding M(R) is removed from the list. For COP-2 only, the M(R)s are multiplexed with N(R) into the REPORT VALUE field of the telemetered CLCW. Since COP-0 and COP-1 only permit frames to be accepted in strict upcounting sequential order, M(R) is not an applicable parameter to those COPs.

(4) FARM-A COUNTER.

The "FARM-A COUNTER" is a FARM-maintained count of the number of Type-A TC Transfer Frames which have been accepted on a given Virtual Channel. Its only use is within COP-0, where the FOP uses implicit techniques to validate sequentiality of the frames that have been accepted by the FARM. For every Type-A TC Frame which passes the FARM-0A Frame Acceptance Checks on a particular Virtual Channel, the FARM-A Counter increments once. Counter

initialization is not required and the counter is permitted to roll over after 256 counts. The value of the FARM-A Counter is reported back in the REPORT VALUE field of the telemetered CLCW and is used by the FOP to determine how many frames have been accepted, and where to begin retransmission in case of error.

(5) FARM-B COUNTER

The "FARM-B COUNTER" is a FARM-maintained count which increments once (in all COPs) each time a Type-B (Bypass-mode) TC Frame is processed by the FARM, having passed the Frame Validation Check on a particular Virtual Channel. Receipt of a valid Type-B frame does not cause any change in V(R), M(R) or the FARM-A COUNTER for that Virtual Channel. The two LSBs of this counter are reported back to the FOP via the FARM-B COUNTER field in the telemetered CLCW.

(6) FOP TRANSMIT TIMER

The "FOP TRANSMIT TIMER" is a time counter which is maintained within the FOP to establish a maximum time interval, after passing a buffer of TC Frame data to the layer below for transmission, by the end of which the FOP expects to have received a status report (CLCW) indicating that:

(a) The physical link has been established, and/or

(b) The Frame data have been received by the FARM.

In the event that the timer runs out without the FOP observing a CLCW confirming (a) above, there is a high probability that a problem exists somewhere within the physical uplink channel which interconnects the FOP and FARM.

When a CLCW acknowledges the occurrence of (a) and/or (b) above before the FOP TRANSMIT TIMER has expired, the timer is canceled. If a CLCW does not confirm the occurrence of (a) and/or (b) above before the timer runs-out, the FOP may proceed with retransmission strategies according to the rules of the particular COP in use: the precise retransmission strategies for each COP are specified in Reference [7].

The FOP TRANSMIT TIMER is started by the act of passing a buffer of TC Frame data from the FOP to the layers below for radiation: the precise mechanisms for starting and stopping the timer may vary between COPs and are specified in Reference [7]. The subsequent mission-defined timer interval is COP-dependent and is a function of such parameters as:

(1) The round trip propagation delay.

(2) The frequency of CLCW sampling.

(3) The time it takes to transmit a maximum length TC Transfer Frame.

(4) The number of Virtual Channels in use.

(5) The prioritization of Missing Frame Reports.

(6) Known delays due to ground or spacecraft data handling and processing.

(7) The uplink bit rate.

(8) A time margin for contingency.

A prerequisite for using the FOP TRANSMIT TIMER is the presence (or expected presence before timer run-out occurs) of a downlink telemetry reporting channel: the timer is not used during "blind" commanding.

(7) FOP SLIDING WINDOW

When operating with Type-A frames in COP-1 or COP-2, a "FOP SLIDING WINDOW" and "FARM SLIDING WINDOW" are basic features of the COP which are used to prevent problems caused by complete "wrap-around" of the transmitted TC FRAME SEQUENCE NUMBER during the period before the FOP TRANSMIT TIMER runs out.

Since the FRAME SEQUENCE NUMBER is only 8 bits long, it will recycle or "wrap-around" every 256 frames. If the spacecraft FARM rejects frame "n" but the FOP keeps transmitting frames because the FOP TRANSMIT TIMER has not run out and it has not seen the rejection via telemetry, a new frame "n" could eventually be sent by the FOP 256 frames later when the FRAME SEQUENCE NUMBER wraps around: this frame would then be accepted by the FARM, which interprets it as the original frame "n", even though it is from the wrong sequence and is actually n+256. The FOP SLIDING WINDOW therefore establishes a "credit" which limits the number of frames which can be transmitted ahead of frame "n" by the FOP before a telemetered CLCW is returned that acknowledges acceptance of frame "n".

As a safety precaution, this Recommendation suggests that a "credit" of no more than 127 TC Transfer Frames be sent by the FOP in advance of the return of the CLCW corresponding to the first frame that was sent on a particular Virtual Channel. When the number of frames equalling the selected FOP SLIDING WINDOW size has been sent without CLCW acknowledgment of the first one sent, the FOP shall halt the transmission of frames to the layer below. Receipt of each next-required CLCW will enable the window to slide and an additional Transfer Frame to be transmitted.

(8) FARM SLIDING WINDOW

The FARM SLIDING WINDOW is a basic feature of COP-1 and COP-2 which provides a safety mechanism that enables the FARM to guard against FRAME SEQUENCE NUMBER wrap-around in the event that the FOP SLIDING WINDOW is not active or malfunctioning.

When a FARM SLIDING WINDOW value of "K" is set into a FARM which expects frame "n", any received frame bearing a FRAME SEQUENCE NUMBER greater than (n+K) will cause the FARM to go into LOCKOUT. Thus if frame "n" is rejected by the FARM but the FOP keeps transmitting because its FOP SLIDING WINDOW is not active, providing that "K" is less than 256, it is impossible for the FARM to keep processing frames until the FRAME SEQUENCE NUMBER wraps around and frame "n+256" is encountered and erroneously accepted.

For COP-1 the sliding window reference point "n" will either correspond to V(R) or (if the FARM SLIDING WINDOW NEGATIVE EDGE feature "NE" is activated) to {V(R)-NE}. For COP-2, "n" will correspond to V(R) or {V(R)-NE} until missing frames exist in the sequence, after which "n" will equal the lowest MISSING FRAME SEQUENCE NUMBER, M(R). CCSDS recommends that a FARM SLIDING WINDOW value of "K" = 127 should be used.

In the case where the sequence number of the TC Transfer Frame violates the FARM SLIDING WINDOW, the FARM shall place itself in a LOCKOUT condition that can only be removed by sending a Type-B UNLOCK Control Command. When in LOCKOUT, all subsequent Type-A frames on a particular Virtual Channel will be rejected until the channel is unlocked by this Type-B Control Command.

(9) FARM SLIDING WINDOW NEGATIVE EDGE

In some cases it may be desirable to send a duplicate frame, i.e., a TC Frame which has the same FRAME SEQUENCE NUMBER as the last frame which was accepted. This may occur if it is desired to increase the probability that a particular critical command is executed, when operating through a potentially unreliable data channel, or if frames are batched together for transmission and it is more convenient to retransmit the whole batch instead of breaking it to retransmit a single internal frame which was rejected.

Duplicate frames will potentially cause problems by violating the FARM SLIDING WINDOW, since FRAME SEQUENCE NUMBERS lower than V(R), or the lowest M(R) for COP-2, will be interpreted as falling outside of the window and will result in LOCKOUT.

To avoid these problems, the FARM may be set up via an optional Control Command so that a FARM SLIDING WINDOW NEGATIVE EDGE is in effect.

The commanded value of the negative edge, "NE", will offset the FARM SLIDING WINDOW (K) in a negative-counting direction from the reference point by NE frames. For COP-1 (and COP-2 with no missing frames) the reference point is V(R), so that any received frame bearing a FRAME SEQUENCE NUMBER less than {V(R)-NE} or greater than {V(R)-NE+K}, modulo 256, will cause the FARM to go into LOCKOUT. For COP-2 with missing frames, the reference point is the lowest M(R).

(10) FARM MISSING FRAME WINDOW

The FARM MISSING FRAME WINDOW is a basic feature only for COP-2, since that COP allows frame acceptance to proceed after one or more frames have been missed. The FARM MISSING FRAME WINDOW provides a mechanism to limit the number of missing frames which will be tolerated on a particular Virtual Channel (e.g., to avoid overloading the capacity of the telemetry system to send M(R) reports back to the FOP).

TC Frames are nominally transmitted with their N(S) values arranged in upcounting sequential order. FARM-2 tracks the SEQUENCE NUMBER of incoming Type-A frames by maintaining an upcounting V(R). The M(R)s of any missing Type-A frames are added to a "missing frames list" which is reported back to the FOP via sequentially telemetered CLCWs.

The FARM MISSING FRAME WINDOW sets a limit to the number of entries on the missing frames list which will be tolerated. Once the number of M(R) entries EQUALS the programmed MISSING FRAME WINDOW, no further missing frames will be tolerated, i.e., the FARM will continue to accept a series of new frames as long as they pass the Frame Acceptance Checks, but as soon as the first Type-A frame is rejected after the window limit is reached then all subsequent Type-A frames will be rejected UNLESS they correspond to one of the retransmitted M(R)s. Subsequent receipt of one or more of the M(R) frames will then reduce the number of missing frames below the MISSING FRAME WINDOW limit, and normal acceptance will resume.

(11) FARM FIXED WINDOW

When operating any FARM in the Type-A (Frame Acceptance Check) mode, the FARM FIXED WINDOW is an optional mechanism which can be activated to automatically CLOSE a Virtual Channel and terminate the associated CLCW reporting once a pre-specified number of Type-A TC Frames that comprise an indicated sequence have been accepted.

Setting the FARM FIXED WINDOW permits the FOP to tell the FARM the total number of Type-A TC Frames that will be transmitted through one particular Virtual Channel during a TC Session. The expected total number of frames is specified via a Control Command to set the FARM FIXED WINDOW at the time that a particular

Virtual Channel is OPENed or MODIFIED. Once the FARM has accepted the expected number of Type-A frames as specified by the FARM FIXED WINDOW, it may automatically CLOSE the Virtual Channel and stop the channel's telemetry reporting. This optional (value-added) feature is available to all COPs and may be useful in situations where telemetry reporting capacity is constrained.

(12) SESSION COUNTER

This is an optional counter that may be used as a value-added feature to speed COP operations when bounded sets of TC data (e.g., TC Files) are being transferred through a particular Virtual Channel. When a Virtual Channel is OPENed with an established FARM FIXED WINDOW, the channel will be automatically CLOSEd once the required number of Type-A frames have been accepted by the FARM. Each time such an automatic Virtual Channel closure occurs, the SESSION COUNTER shall increment once to provide the FOP with positive indication that this is the reason CLCWs no longer appear for that Virtual Channel. The three least significant bits of the Session Counter may be reported in the mission-specified STATUS FIELD of the telemetered CLCW.

4.3.3.2 COP-0 Definition. COP-0 is a closed-loop telecommanding protocol within which control of sequentiality is provided by the sending-end FOP rather than the receiving-end FARM; therefore numbering of frames by the FOP is unnecessary. The FRAME SEQUENCE NUMBER field must be present in every TC Frame, but since it is unused by the FARM its contents are set by convention to value "all zeros". Within COP-0 all Type-A frames are distributed within the spacecraft in the order in which they are transmitted by the FOP.

FARM-0 submits each received frame to the standard Frame Validation Check that is defined in Section 4.3.2. Any Type-B frame which passes the validation check is distributed on its appropriate Virtual Channel and the FARM-B COUNTER is incremented. Any Type-A frame which passes the validation check is distributed on its appropriate Virtual Channel and the FARM-A COUNTER is incremented.

Any Type-A or Type-B frame which fails the Frame Validation Check shall be discarded, and FARM-0 shall immediately enter LOCKOUT to prevent the acceptance of further Type-A frames on ANY Virtual Channel: this is necessary since the FARM has no knowledge of the Type or Virtual Channel assignment of the erroneous frame; therefore all Virtual Channels must be locked out to preserve sequentiality. Any subsequent Type-B frame which passes the Frame Validation Check will be processed normally. The LOCKOUT mode for Type-A frames will remain in effect until it is cleared by reception of a Type-B UNLOCK Control Command: only one UNLOCK Control Command is required to resume operation on all Virtual Channels. In the event of an observed LOCKOUT, FOP-0 may be directed (by the layer above, or as a negotiated default) to respond by executing one of three optional retransmission strategies:

(a) Within the first option, FOP-0 ceases the transmission of frames to the layer below, calculates the number of frames which were accepted by the FARM prior to the failure (by subtracting the initial value of the FARM-A COUNTER or FARM-B COUNTER from its current value) and "goes-back-n" to resume transmission from the point of failure. The first frame of the retransmitted batch must be a Type-B UNLOCK Control Command. In order to simplify the retransmission logic, Type-B frames should not otherwise be interleaved with Type-A's, since this will enable the FOP to use either the FARM-A COUNTER, or the FARM-B COUNTER (but not both), in the "go-back-n" calculation.

(b) Within the second option, when a LOCKOUT is detected, FOP-0 ceases all operations and alerts a higher-layer authority, which must direct the appropriate corrective action.

(c) Within the third option FOP-0 may transmit the frames during one session as a series of one or more batches. Upon detection of a LOCKOUT associated with any batch, the entire batch is retransmitted, preceded by a Type-B UNLOCK Control Command. This option may result in duplicate frames being accepted and distributed by the FARM.

Acceptance of a Type-A frame on a particular Virtual Channel by FARM-0 causes the following actions:

A. The value of the FARM-A COUNTER shall increment by one, and

B. The CLCW parameters for that Virtual Channel shall be updated.

Receipt of a valid Type-B frame on a particular Virtual Channel by FARM-0 causes the following actions:

C. The FARM-B COUNTER shall increment by one, and

D. The CLCW parameters for that Virtual Channel shall be updated.

Since any frame which fails a Frame Validation Check will cause FARM-0 to enter LOCKOUT and reject all subsequent Type-A frames REGARDLESS OF THEIR VIRTUAL CHANNEL, any error in any frame will effectively stop the entire flow of telecommands on all Virtual Channels which use COP-0 until corrected.

The applicability of the available counters, numbers and windows to COP-0 is as follows:

FARM-A COUNTER: use of this counter is a basic feature within COP-0.

FRAME SEQUENCE NUMBER, N(S): all TC Frames transmitted within COP-0 must have a Frame Sequence Number, but since the field is ignored by FARM-0 it shall by convention be set to value "all zeros".

NEXT EXPECTED FRAME SEQUENCE NUMBER, V(R): this number is not used within COP-0.

MISSING FRAME SEQUENCE NUMBER, M(R): this number is not used within COP-0, since no missing frames can be tolerated during transfer and sequence numbering is not used by FARM-0.

FARM-B COUNTER: use of this counter is a basic feature within COP-0.

SESSION COUNTER: use of this counter is not a basic feature within COP-0.

FOP TRANSMIT TIMER: use of this timer is a basic feature within COP-0.

FOP SLIDING WINDOW: use of this window is not a basic feature within COP-0.

FARM SLIDING WINDOW: not applicable to COP-0.

FARM SLIDING WINDOW NEGATIVE EDGE: not applicable to COP-0.

FARM FIXED WINDOW: use of this window is not a basic feature within COP-0.

MISSING FRAME WINDOW: not applicable to COP-0.

4.3.3.3 COP-1 Definition. COP-1 is a closed-loop telecommanding protocol which utilizes sequential ("go-back-n") retransmission techniques to correct TC Frames which were rejected by the spacecraft because of error. Receiving-end storage is not provided within FARM-1, therefore COP-1 only allows Type-A TC Frames to be accepted by the spacecraft if they are received in strict sequential order, and their contents are immediately passed on to the layer above.

Within COP-1, control of sequentiality is provided by the FARM instead of the FOP, and therefore frame sequence numbering is explicit. The FRAME SEQUENCE NUMBER must be present in each frame, and Type-A frames must be transmitted by the FOP with their numbers arranged in strict upcounting order. By convention, Type-B frames must always have their N(S) set to value "zero".

FARM-1 first submits each frame to the standard Frame Validation Check: any frame which fails this validation check shall be discarded, but (unlike FARM-0) no other actions occur and the FARM does NOT go into LOCKOUT. Any Type-B frame which passes the Frame Validation Check will be immediately accepted.

Provided the FARM on a particular Virtual Channel is not in LOCKOUT, a valid Type-A frame will be accepted if it passes the following additional Frame Acceptance Check:

(1) N(S) shall equal V(R)

Any Type-A frame which fails the Frame Acceptance Check shall be discarded: if its FRAME SEQUENCE NUMBER N(S) is within the FARM SLIDING WINDOW (and in the positive-counting direction from the reference point), the RETRANSMIT flag in the CLCW shall be set to value "1" for that Virtual Channel. The RETRANSMIT flag for a Virtual Channel shall be reset to value "0" when a Type-A frame is accepted.

If FARM-1 is in LOCKOUT, all incoming Type-A frames on that Virtual Channel shall be rejected until the LOCKOUT is reset by transmission of a Type-B UNLOCK Control Command. Conditions which cause FARM-1 to enter LOCKOUT are:

(a) The FARM FIXED WINDOW is active and N(S) exceeds its allowable range, or

(b) The FARM SLIDING WINDOW is active, and N(S) falls outside its allowable range, i.e., {V(R) + K}, modulo 256, or {V(R) - NE + K} if the Negative Edge feature is set.

Acceptance of a Type-A frame on a particular Virtual Channel by FARM-1 causes the following actions:

A. The value of V(R) shall increment by one, and

B. The CLCW parameters for that Virtual Channel shall be updated.

Receipt of a valid Type-B frame on a particular Virtual Channel by FARM-1 causes the following actions:

C. V(R) shall not change, and

D. The FARM-B COUNTER shall increment by one, and

E. The CLCW parameters for that Virtual Channel shall be updated.

Within the transmission of a set of frames under COP-1, their FRAME SEQUENCE NUMBERS shall be arranged into proper upcounting sequence by the FOP, which passes the sequentially numbered frames to the Channel Service for transmission to the spacecraft.

During FARM-1 processing, any frame which fails the Frame Validation Check is discarded. A valid Type-A frame can only pass the Frame Acceptance Check if its FRAME SEQUENCE NUMBER N(S) is the same as the NEXT EXPECTED FRAME SEQUENCE NUMBER V(R). Therefore out of sequence frames will be discarded. The FARM continuously returns the number of the latest V(R) to the FOP via the telemetered N(R) measurement in the CLCW.

The FOP monitors the CLCW to verify the smooth progression of N(R) increments, and to check that the RETRANSMIT and LOCKOUT flags remain set to value "0".

If the FOP detects that N(R) stops incrementing, indicating that V(R) has also stopped incrementing (accompanied by a RETRANSMIT flag), or that a LOCKOUT exists, it immediately stops passing frames to the Channel Service. It must then transmit and verify a Type-B UNLOCK Control Command to FARM-1, if required. The FOP goes-back-"n" frames to find the frame whose N(S) matches V(R), and resumes transmission from this point. When the spacecraft receives the valid Type-A frame whose N(S) matches V(R), the FARM will accept this frame and the RETRANSMIT flag in the CLCW will be reset to value "0".

Type-B frames shall always, by convention, have their N(S) set to value "zero". Control Commands are sent in the Type-B mode: considering that Type-B frames are not subjected to any Frame Acceptance Check, Type-BC Control Commands should be used with caution, since the only indication of their rejection is an incorrect number of increments in the FARM-B COUNTER within the CLCW. Type-BD frames may be used in emergency conditions to "force in" data-carrying frames without regard for their sequentiality or for the various windows which may be in effect. Such emergencies may involve open-loop FOP procedures (i.e., blind commanding with no telemetry stream available).

Because COP-1 locates the sequentiality check within the FARM, it is possible to operate each Virtual Channel independently, i.e., one Virtual Channel may be in a RETRANSMIT or LOCKOUT condition, but commanding through another Virtual Channel may still be performed.

The applicability of the available counters, numbers and windows to COP-1 is as follows:

FARM-A COUNTER: this counter is not used by COP-1.

FRAME SEQUENCE NUMBER, N(S): use of this number is a basic feature within COP-1. Type-A frames shall be numbered according to the upcounting sequential order in which their data contents shall be delivered to the layer above, and it is required that they be internally transmitted in this order within the Transfer layer.

NEXT EXPECTED FRAME SEQUENCE NUMBER, V(R): use of this number is a basic feature within COP-1.

MISSING FRAME SEQUENCE NUMBER, M(R): this number is not used by COP-1, since no missing frames can be tolerated by FARM-1.

FARM-B COUNTER: use of this counter is a basic feature within COP-1.

SESSION COUNTER: use of this counter is not a basic feature within COP1.

FOP TRANSMIT TIMER: use of this timer is a basic feature within COP-1.

FOP SLIDING WINDOW: use of this window is a basic feature within COP-1.

FARM SLIDING WINDOW: use of this window is a basic feature within COP-1. Any violation of the FARM Sliding Window by a Type-A frame shall cause FARM-1 on that Virtual Channel to go into LOCKOUT state.

FARM SLIDING WINDOW NEGATIVE EDGE: use of this parameter is a basic feature within COP-1.

FARM FIXED WINDOW: use of this window is not a basic feature within COP-1. If used, then any violation of the FARM Fixed Window (caused by receipt of a Type-A frame bearing an N(S) which exceeds the range allowed by the window) shall cause FARM-1 on that Virtual Channel to go into LOCKOUT state.

MISSING FRAME WINDOW: not applicable to COP-1.

4.3.3.4 COP-2 Definition. COP-2 is a closed-loop telecommanding protocol which utilizes selective retransmission techniques to correct frames which were rejected by the spacecraft because of error. Receiving-end storage is provided within FARM-2, therefore COP-2 allows Type-A TC Frames to be accepted by the spacecraft if they are received in non-sequential order, subject to certain constraints. The storage is used to hold an incomplete series of received frames until all of the missing pieces have been received, at which time their data contents will be delivered to the layer above. Within COP-2, control of sequentiality is provided by the FARM, and therefore frame sequence numbering is explicit. The FRAME SEQUENCE NUMBER must be present in each frame, and Type-A frames are nominally transmitted by the FOP with their numbers arranged in upcounting order. However, the FOP may interleave retransmitted frames and newly transmitted frames so that sequence discontinuities are noted by FARM-2.

FARM-2 first submits each frame to the standard Frame Validation Check: any frame which fails this validation check shall be discarded, but no other actions occur and the FARM does not go into LOCKOUT. Any Type-B frame which passes the Frame Validation Check will be immediately accepted.

Provided that the FARM is not in LOCKOUT on a Virtual Channel, a valid Type-A frame will be accepted if it passes the following Frame Acceptance Check:

(1) N(S) shall be equal to or greater than V(R), but less than the lowest number above V(R) which is allowed by either the FARM SLIDING WINDOW, the FARM MISSING FRAME WINDOW, or the FARM FIXED WINDOW, or

(2) N(S) equals one of the missing M(R)s.

Any Type-A frame which fails the Frame Acceptance Check shall be discarded, and the RETRANSMIT flag in the CLCW for that Virtual Channel shall be set to value "1". The

RETRANSMIT flag shall only be reset to value "0" when a Type-A frame is accepted and no missing frames exist in the series accepted so far on that Virtual Channel.

If the FARM is in LOCKOUT, all incoming Type-A frames on that Virtual Channel shall be rejected and discarded until the LOCKOUT is reset via a Type-B UNLOCK Control Command. Conditions which cause a LOCKOUT are:

(a) The FARM FIXED WINDOW is active and N(S) exceeds its allowable range, or

(b) The FARM SLIDING WINDOW "K" is active, and N(S) is greater than the lowest {M(R) + K}, modulo 256, or (if no frames are currently missing) N(S) is greater than {V(R) + K}, modulo 256. If the FARM SLIDING WINDOW NEGATIVE EDGE feature is set, the appropriate NE offset shall apply.

FARM-2 shall maintain the V(R) and M(R) numbers. Acceptance of a Type-A frame by FARM-2 causes the following actions:

A. If N(S) equals V(R), the new V(R) shall equal {N(S)+1} and the CLCW parameters for that Virtual Channel shall be updated.

B. If N(S) is greater than V(R), but it is within the FARM SLIDING or FIXED WINDOWS and does not violate the MISSING FRAME WINDOW, the new V(R) is set to {N(S)+1}, and the sequence numbers of the missing frames between and including {N(S)-1} and the previous V(R) are added as individual M(R) entries on a missing frames list. Each M(R) entry on the list shall cause the CLCW parameters for that Virtual Channel to be updated.

C. If N(S) equals M(R), that M(R) is removed from the list of missing frames. If no more M(R)s remain in the list, the RETRANSMIT flag shall be reset to "0" in the CLCW parameter field.

IT SHOULD BE NOTED THAT IF THE MISSING FRAME WINDOW IS SET TO "0", FARM-2 IS FUNCTIONALLY IDENTICAL TO FARM-1.

Receipt of a valid Type-B frame causes the following actions:

D. V(R) and M(R) shall not change, and

E. The FARM-B COUNTER shall increment by one, and

F. The CLCW parameters for that Virtual Channel shall be updated.

Within the original transmission of a set of frames under COP-2, their FRAME SEQUENCE NUMBERS shall be arranged into proper upcounting sequence by the FOP. Frames which fail the Frame Validation Check will be discarded by FARM-2. Valid Type-A frames which pass the Frame Acceptance Check, and valid Type-B frames, will be accepted.

Missing Type-A frames detected by FARM-2 will be reported to the FOP as M(R) reports in the telemetered CLCW. The order of transmitting the CLCWs shall be to report all of the M(R)s first, beginning with the "oldest" missing frame, stepping up through the list to the most recent M(R), and finally reporting V(R) before repeating the cycle. Any missing Type-A frames will be selectively retransmitted by the FOP, which interleaves them on a priority basis non-sequentially with newly transmitted frames. The "oldest" missing frames shall be retransmitted first.

Whenever the number of M(R) entries on the missing frames list for a particular Virtual Channel equals the Missing Frame Window, FARM-2 shall only accept Type-A frames with N(S)=M(R) or N(S)=V(R), until the number of entries on the list is again below the window threshold. Any other Type-A frame shall be rejected. If the total number of entries on the missing frames list does NOT exceed the Missing Frame Window, FARM-2 shall reject any Type-A frame if its N(S) is not one of the M(R)s and is greater than V(R) by an amount which would cause enough new M(R) entries to be added to the missing frame list to equal the Missing Frame Window.

Missing Type-B frames will be detected by the FOP by observing an incorrect number of increments in the FARM-B COUNTER within the CLCW. Since Type-B frames are not numbered (by convention they always have their N(S) set to value "zero"), automatic retransmission of missing Type-B's is not possible, and the FOP must alert a higher layer authority to take appropriate action.

Control Commands are sent as Type-B frames: considering that Type-B frames are not subjected to any Frame Acceptance Check, Type-BC Control Commands should be used with caution, since the only indication of their rejection is an incorrect number of increments in the FARM-B COUNTER within the CLCW. Type-BD frames may be used in emergency conditions to "force in" data-carrying frames without regard for their sequentiality or for the various windows which may be in effect. Such emergencies may involve open-loop FOP procedures (i.e., blind commanding with no telemetry stream available).

Because COP-2 locates the sequentiality check within the FARM, it is possible to operate each Virtual Channel independently, i.e., one Virtual Channel may be in a RETRANSMIT or LOCKOUT condition, but commanding through another Virtual Channel may still be performed.

The applicability of the available counters, numbers and windows to COP-2 is as follows:

FARM-A COUNTER: this counter is not used by COP-2.

FRAME SEQUENCE NUMBER, N(S): use of this number is a basic feature within COP-2. Type-A frames shall be numbered according to the upcounting sequential order in which their data contents shall be delivered to the layer above, though it is not required that they be internally transmitted in this order within the Transfer layer.

NEXT EXPECTED FRAME SEQUENCE NUMBER, V(R): use of this number is a basic feature within COP-2.

MISSING FRAME SEQUENCE NUMBER, M(R): use of this number is a basic feature within COP-2. A list of missing frame sequence numbers, M(R), shall be maintained by FARM-2. Any frame retransmitted by the FOP with an N(S) less than V(R), but equal to one of the M(R)s, shall be accepted and shall cancel the corresponding M(R).

FARM-B COUNTER: use of this counter is a basic feature within COP-2.

SESSION COUNTER: use of this counter is not a basic feature within COP-2.

FOP TRANSMIT TIMER: use of this timer is a basic feature within COP-2, providing that propagation delays are short enough to make its use feasible.

FOP SLIDING WINDOW: use of this window is a basic feature within COP-2, providing that propagation delays are short enough to make its use feasible.

FARM SLIDING WINDOW: use of this window is a basic feature within COP-2. Any violation of the Sliding Window by a Type-A frame shall cause FARM-2 to go into LOCKOUT state for that Virtual Channel.

FARM SLIDING WINDOW NEGATIVE EDGE: use of this feature is not a basic feature within COP-2.

FARM FIXED WINDOW: use of this window is not a basic feature within COP-2. If used, any violation of the Fixed Window by a Type-A frame shall cause FARM-2 to go into LOCKOUT state for that Virtual Channel.

MISSING FRAME WINDOW: use of this window is a basic feature within COP-2.

ANNEX A

DATA ROUTING SERVICE ACRONYMS AND TERMINOLOGY

(THIS ANNEX **IS** PART OF THE RECOMMENDATION)

Purpose:

This Annex defines the key acronyms and terms which are used throughout this Recommendation to describe activities within the Segmentation and Transfer Layers.

A C R O N Y M S

A:	ACCEPTANCE CHECK MODE
B:	BYPASS MODE
CCSDS:	CONSULTATIVE COMMITTEE FOR SPACE DATA SYSTEMS
CLCW:	COMMAND LINK CONTROL WORD
COP:	COMMAND OPERATION PROCEDURE
COP-0:	COMMAND OPERATION PROCEDURE #0
COP-1:	COMMAND OPERATION PROCEDURE #1
COP-2:	COMMAND OPERATION PROCEDURE #2
CTRL:	CONTROL
FARM:	FRAME ACCEPTANCE AND REPORTING MECHANISM
FARM-A:	FARM ACCEPTANCE CHECK MODE
FARM-B:	FARM BYPASS MODE
FARM-0:	FARM PART OF COP-0
FARM-1:	FARM PART OF COP-1
FARM-2:	FARM PART OF COP-2
FARM-0A:	FARM-0, ACCEPTANCE MODE
FARM-1A:	FARM-1, ACCEPTANCE MODE
FARM-2A:	FARM-2, ACCEPTANCE MODE
FARM-0B:	FARM-0, BYPASS MODE
FARM-1B:	FARM-1, BYPASS MODE
FARM-2B:	FARM-2, BYPASS MODE
FARM-0AD:	FARM-0, ACCEPTANCE MODE, DATA CARRYING
FARM-0BD:	FARM-0, BYPASS MODE, DATA CARRYING
FARM-0BC:	FARM-0, BYPASS MODE, CONTROL COMMAND
FARM-1AD:	FARM-1, ACCEPTANCE MODE, DATA CARRYING
FARM-1BD:	FARM-1, BYPASS MODE, DATA CARRYING
FARM-1BC:	FARM-1, BYPASS MODE, CONTROL COMMAND
FARM-2AD:	FARM-2, ACCEPTANCE MODE, DATA CARRYING
FARM-2BD:	FARM-2, BYPASS MODE, DATA CARRYING
FARM-2BC:	FARM-2, BYPASS MODE, CONTROL COMMAND
FOP:	FRAME OPERATION PROCEDURE
FOP-0:	FOP PART OF COP-0
FOP-1:	FOP PART OF COP-1
FOP-2:	FOP PART OF COP-2
ID:	IDENTIFIER
K:	SLIDING WINDOW WIDTH
MAP:	MULTIPLEXER ACCESS POINT
M(R):	MISSING FRAME SEQUENCE NUMBER
MSB:	MOST SIGNIFICANT BIT
NE:	NEGATIVE EDGE OF FARM SLIDING WINDOW
N(R):	THE OBSERVED VALUE OF V(R) CONTAINED IN ONE CLCW
N(S):	TRANSMITTED FRAME SEQUENCE NUMBER
QOS:	QUALITY OF SERVICE

RF or rf:	RADIO FREQUENCY
TC:	TELECOMMAND
TF:	TRANSFER FRAME
VC:	VIRTUAL CHANNEL
V(R):	NEXT EXPECTED FRAME SEQUENCE NUMBER

TERMINOLOGY

CLOSE:

A Control Command which deactivates a Virtual Channel and causes all CLCW reporting to be suspended.

COMMAND LINK CONTROL WORD (CLCW):

The CLCW is the protocol data unit for TC reporting via telemetry from the FARM back to the FOP. The CLCW resides wholly within the Transfer layer, though it does include a few parameters describing the readiness state of lower layers, which aid the efficient operation of the COP. The CLCW does not perform any reporting service for the Segmentation layer.

COMMAND OPERATION PROCEDURE (COP):

A sequence of procedural activities designed to assure the reliable, error-controlled delivery of a TC Transfer Frame across the Transfer layer. The COP is comprised of a Frame Operation Procedure (FOP) operating within the sending end of the layer and a Frame Acceptance and Reporting Mechanism (FARM) operating within the receiving end of the layer.

COP-0 = Sequential acceptance and retransmission without frame sequence numbering.

COP-1 = Sequential acceptance and retransmission with frame sequence numbering.

COP-2 = Sequence independent acceptance, and selective retransmission, with frame sequence numbering.

CONTROL COMMAND:

A special Type-B TC Frame which carries control instructions in its Data Field to set up the internal operating parameters of the FARM.

CONTROL INSTRUCTION:

Information that is required to set up a TC System layer to support the handling of telecommands.

DATA START:

A signal from the layer below which becomes "true" to notify the Transfer layer that valid decoded data octets are being transferred.

DATA STOP:

A signal from the layer below corresponding to Data Start becoming "false", which notifies the Transfer layer that no more valid data octets are being transferred by the layer below.

DUMP VIRTUAL CHANNEL STATUS:

A Control Command which initiates a complete cycle of CLCW reports from ALL Virtual Channels implemented on a particular spacecraft.

FARM-A COUNTER:

A counter, reported in the CLCW, which increments once for every Type-A frame that is accepted by the FARM on a particular Virtual Channel.

FARM-B COUNTER:

A counter, reported in the CLCW, which increments once for every Type-B frame that is accepted by the FARM on a particular Virtual Channel.

FARM FIXED WINDOW:

A mechanism which can be activated to automatically close a Virtual Channel and terminate the associated CLCW reporting once the correct number of Type-A TC Frames comprising an indicated sequence have been accepted by the FARM.

FARM SLIDING WINDOW:

A safety device within the FARM to prevent wrap-around of the transmitted FRAME SEQUENCE NUMBERS in case the FOP SLIDING WINDOW fails or is inactive. If a frame is received with a FRAME SEQUENCE NUMBER N(S) greater than the limit established by the FARM SLIDING WINDOW, the FARM will place itself in a LOCKOUT mode.

FARM SLIDING WINDOW NEGATIVE EDGE:

A mechanism for offsetting the FARM SLIDING WINDOW.

FILL DATA:

Extra trailing octets of meaningless data sent to the Transfer layer by the layer below as a result of the mechanization of that lower layer. Fill must be removed by the Transfer layer.

FOP SLIDING WINDOW:

A mechanism used to prevent a complete "wrap-around" of the transmitted frame sequence numbers inside the time-out window before a CLCW is returned to the FOP.

FOP TRANSMIT TIMER:

A time interval after transmitting a frame by the limit of which the FOP expects to have received a status report (CLCW) concerning that frame from the FARM.

FRAME ACCEPTANCE CHECK:

A further set of sequence tests to which Type-A frames are subjected when they pass the Frame Validation Check. Frames which fail the Acceptance Check are rejected.

FRAME ACCEPTANCE AND REPORTING MECHANISM (FARM):

The FARM is the set of procedures executed by the receiving end of the Transfer layer to decide whether to accept a TC Transfer Frame and how to report operation and status back to the FOP via Command Link Control Words.

FRAME OPERATION PROCEDURE (FOP):

The FOP is the procedure executed by the sending end of the Transfer layer to transmit a TC Transfer Frame. The FOP conducts a transfer sequence using the communication services of the underlying TC Channel Service. Actions of the FOP are dictated by the rules of the COP to which it belongs and the FARM status information passed back to it via the telemetered Command Link Control Word (CLCW).

FRAME SEQUENCE NUMBER N(S):

The upcounting absolute number that is placed into each Type-A TC Frame when operating within COP-1 or COP-2. The field is present in COP-0 frames, but is not used and is set to value "zero".

FRAME VALIDATION CHECK:

A set of common integrity and quality tests to which ALL frames are first subjected when they are processed by the receiving end of the Transfer layer.

LOCKOUT:

A condition whereby the FARM has detected a severe sequentiality anomaly and rejects all subsequent Type-A frames until reset by a Type-B UNLOCK Control Command.

MISSING FRAME SEQUENCE NUMBER M(R):

The Frame Sequence Number of any Type-A frame which is detected by the FARM to be missing in the upcounting sequence when using COP-2.

MISSING FRAME WINDOW:

A mechanism for instructing the FARM to only permit a limited number of missing frames to be tolerated, e.g., when telemetry reporting is limited. When the number of missing frames within a given sequence equals the Missing Frame Window, no further Type-A frames will be accepted which would cause the window to be exceeded.

MODIFY:

A Control Command which modifies the operational windows and numbers within the FARM on an OPEN Virtual Channel.

MULTIPLEXER ACCESS POINT (MAP):

A MAP is a mechanism provided within the Segmentation layer to allow different user data structures to be multiplexed together for transmission on one Virtual Channel provided by the layer below. Multiplexing allows user data structures with different delivery priorities to share the same Virtual Channel and thus provides flow control.

NEXT EXPECTED FRAME SEQUENCE NUMBER V(R):

The value of the Frame Sequence Number, N(S), which the FARM expects to see in the next Type-A frame in order to preserve upcounting sequence.

NEXT EXPECTED FRAME SEQUENCE NUMBER N(R):

The observed current value of V(R) that is telemetered from the FARM to the FOP via each CLCW.

OPEN:

A Control Command which authorizes use of a Virtual Channel and programs certain operational windows and numbers into the FARM. Within an OPEN Virtual Channel the FARM transmits CLCWs to the FOP via telemetry.

RESUME:

A Control Command which unfreezes a SUSPENDed Virtual Channel in its prior configuration, and restores normal CLCW reporting priority.

RETRANSMIT:

A flag indication from the FARM, contained in a CLCW, that at least one Type-A frame has been rejected and that retransmission is required from the FOP.

SEGMENTATION LAYER:

The top layer of the Data Routing Service, which interfaces user data structures with the protocols used during transfer to the receiving spacecraft.

SESSION:

A Session is established to transfer all of the telecommands required to execute a specific set of actions that implement a particular phase of the mission profile.

SESSION COUNTER:

An optional counter, reported in the CLCW, which increments once each time any Virtual Channel transitions from the OPEN to the CLOSED state.

SUSPEND:

A Control Command which freezes the operation of an OPEN Virtual Channel in its current state, places the Virtual Channel in LOCKOUT, and reduces its CLCW reporting priority.

TELECOMMAND SEGMENT (TC SEGMENT):

The protocol data unit of the TC Segmentation layer. TC Segments consist of a Segment Header and Segment Data Field.

TELECOMMAND TRANSFER FRAME (TC TRANSFER FRAME or TC FRAME):

The protocol data unit of the Transfer layer. TC Transfer Frames contain a Frame Header, a Frame Data Field, and an optional Frame Error Control Field. The Data Field carries either a TC User Data Unit (e.g., TC Segments or TC Packets), or Control Commands which establish the internal operations of the Transfer layer.

TRANSFER LAYER:

The bottom layer of the Data Routing Service, which performs the transfer of user data structures to the receiving spacecraft.

TYPE-A (ACCEPTANCE MODE) FRAMES:

TC Transfer Frames which have a flag set indicating that they are to be tested against the Frame Acceptance Check.

TYPE-B (BYPASS MODE) FRAMES:

TC Transfer Frames which have a flag set indicating that they are NOT to be tested against the Frame Acceptance Check, but may be delivered as soon as they pass the Frame Validation Check.

TC USER DATA UNIT:

A finite-length user data structure carried within the FRAME DATA FIELD of a TC Transfer Frame. If the layers above the Transfer layer conform to the CCSDS telecommand architecture, the TC User Data Unit will correspond to a TC Packet or a TC Segment. If the layers above the Transfer layer do not conform to the CCSDS telecommand architecture, the TC User Data Unit may be any other higher-layer user data structure.

UNLOCK:

A Type-B Control Command which resets a FARM LOCKOUT condition.

VIRTUAL CHANNEL (VC):

Virtual Channels are provided by the Transfer layer, which interfaces with the single physical channel in the layers below and presents the service of apparently separating this single channel into multiple "virtual" paths to the layer above (e.g., the Segmentation layer).

A Virtual Channel (VC) is simply a unique, multi-bit ID code assigned to a particular sequence of TC Transfer Frames to enable all the frames which are members of that sequence to be identified. When different Virtual Channel IDs are assigned to different TC Transfer Frame sequences, the sequences can be multiplexed onto the physical channel at the sending end and then sorted at the receiving end back into their proper parent sequences. Necessarily, when Virtual Channels are not used, the physical channel in concept is the same as one Virtual Channel. Virtual Channels provide an alternative method for multiplexing user data structures if the Segmentation layer is null.

WAIT:

An indication from the FARM, contained in a CLCW, that the receiving end of the Transfer layer has encountered congestion in passing data to the layer above, and cannot accept any more frames.

ANNEX B

DATA ROUTING SERVICE SPECIFICATION

(THIS ANNEX **IS** PART OF THE RECOMMENDATION)

Purpose:

This Annex provides the detailed specification of the service provided by the Segmentation and Transfer layers.

B-1 OVERVIEW OF THE LAYERS WITHIN THE DATA ROUTING SERVICE

The Data Routing Service is implemented using two layers of protocol: the Segmentation layer and the Transfer layer. The function of the Segmentation layer is to prepare user telecommand messages for transmission to the spacecraft, using services of the Transfer layer, by breaking them into TC User Data Units. The function of the Transfer layer is to reliably move Transfer Frames carrying TC User Data Units from the sending end of the Telecommand System to the receiving end, using the Channel Service, including retransmission of any frames which were found by the receiving end to have been damaged during transfer.

A diagram defining the principal elements within the Data Routing Service is presented in Figure B-1.

Higher layer TC User Data Units (e.g., TC Packets) may be long data structures. The characteristics of the physical data channel which interconnects the sending and receiving end of the system are such that the most effective method of transmission requires relatively short data structures. Furthermore, since this physical data channel has a finite data-carrying capacity, a method must be provided to prevent one user from monopolizing the channel to the exclusion of others. The task of the Data Routing Service is therefore to provide the transformation between the characteristics of the user layers of the TC System and the constraints of the physical channel, including breaking large user messages into smaller communications-oriented pieces and multiplexing these pieces to provide responsive virtual access to the channel for all users.

B-2 TC SEGMENTATION LAYER SERVICE SPECIFICATION

The services provided by the Telecommand Segmentation layer are as follows:

(1) The layer breaks long user data structures from the layer above (i.e., TC Packets, or other user data structures which have been generated by a non-standard higher layer) into pieces ("TC User Data Units") which will fit the data field of TC Transfer Frames, and reassembles them after passage through the Transfer layer.

(2) The layer provides a mechanism for multiplexing different segmented TC User Data Units together onto a single Virtual Channel, for the purpose of flow control.

The Segmentation service described in this Recommendation is designed to support the standard CCSDS telecommand Packetization layer (Reference [3]). It can also provide services to other non-standard higher layer TC processes as long as the interface requirements of the Segmentation layer are satisfied.

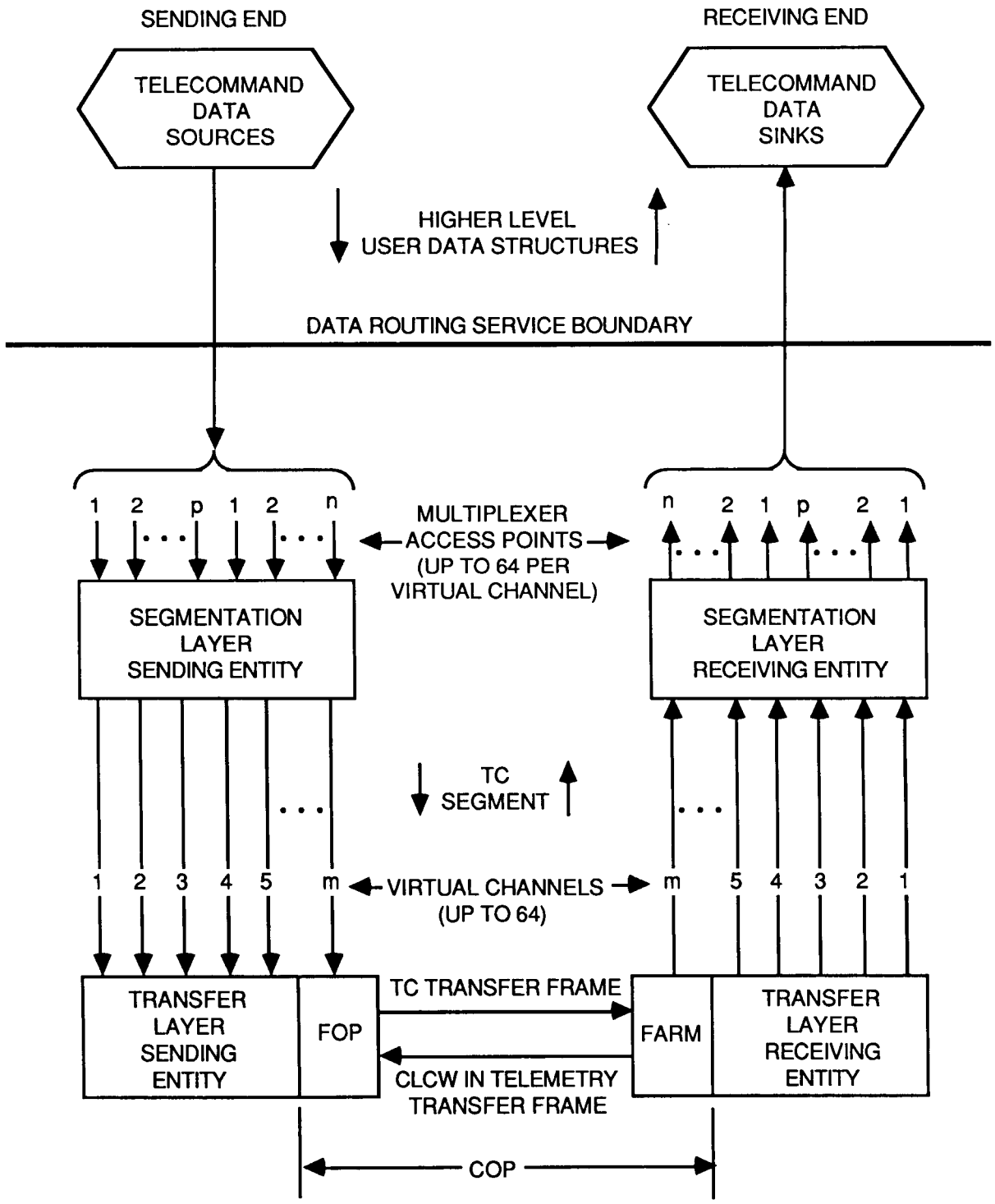


Figure B-1: TC Data Routing Service Elements

B-2.1 Segmentation Layer: Sending End Service Specification

(1) INPUTS

From the layer above:

(a) Transportable user telecommand data structures (e.g., TC Packets) which are to be routed to the spacecraft. The length of the user data structures is unconstrained; however, if they are TC Packets, then they will have a maximum length of 216 octets.

(b) Control instructions which are required in order to transfer the user data structures to the spacecraft, formatted in a CCSDS standard data interchange structure as described in Reference [2]. Those control instructions specifying delivery priority are read and processed by the Segmentation layer and establish the multiplexing hierarchy within this layer. Other control instructions (e.g., directives to abort specific commands) are passed through to the layer below.

NOTE: The abstract content and concrete format of the CCSDS standard data interchange structures containing control instructions are not presently specified herein, and remain an item for potential future extension of this document.

From the receiving end of the layer:

None.

From the layer below:

(c) Information describing the status of transfer of Segments through a given Virtual Channel.

(2) OUTPUTS

To the layer above:

(a) Information describing the status of transfer of sets of user telecommand data structures.

To the receiving end of the layer:

None.

To the layer below:

(b) User data structures which have been broken into TC User Data Units (TC Segments).

(c) Control instructions, contained in a CCSDS standard data interchange structure and possibly passed through from the layer above.

(3) INTERNAL FUNCTIONS

(a) Assigns individual user data structures (e.g., TC Packets or TC Files) to particular Multiplexer Access Points (MAPs) for routing to the spacecraft through a Virtual Channel (VC) provided by the layer below.

(b) Breaks the user data structures into pieces (TC User Data Units) which are compatible with insertion into the data field of the protocol data unit of the layer below (e.g., a TC Transfer Frame).

(c) Labels each TC User Data Unit with sequence control and MAP identification information to create a TC Segment.

(d) Multiplexes TC Segments from different MAPs together onto one Virtual Channel for flow control purposes.

(e) Monitors the process of transferring TC Segments through Virtual Channels by the layer below, and maintains cognizance of the status and availability of particular VCs.

B-2.2 Segmentation Layer: Receiving end Service Specification

(1) INPUTS

From the layer above:

(a) Information concerning the ability of the layer to accept more data.

From the sending end of the layer:

None.

From the layer below:

(b) TC Segments, in sequence and complete, without omission or duplication.

(2) OUTPUTS.

To the layer above:

(a) Reconstructed user data structures (e.g., TC Packets or TC Files), in sequence and complete, without omission or duplication.

To the sending end of the layer:

None.

To the layer below:

(b) Information concerning the ability of the layer to accept more data.

(3) INTERNAL FUNCTIONS

(a) Receives TC Segments from the layer below, delivered on individual Virtual Channels.

(b) Sorts TC Segments associated with individual VCs according to their MAP identifier, and reassembles the Segments associated with a particular MAP to reconstruct the user data structure.

(c) Determines when all TC Segments associated with a particular user data structure have been received correctly.

(d) Passes the reconstructed user data structure (e.g., TC Packet or TC File) to the layer above in sequence, complete and without omission or duplication.

B-3 TC TRANSFER LAYER SERVICE SPECIFICATION

The service provided by the TC Transfer Frame layer is to encapsulate segmented TC User Data Units within a suitable data structure (i.e., a TC Transfer Frame) for transmission through the physical channel which interconnects the sending and receiving ends of the TC System, and to reliably convey them without detected error from the sending to the receiving ends of the layer.

When the layer below is operating at or above a minimum performance level known as "Command Threshold", the Transfer layer shall operate at the following nominal performance points:

(1) The TC Transfer Frame rejection rate shall be less than one rejected Transfer Frame per 10^3 frames that are transmitted. Methods for achieving this within the layer below are defined in Reference [4].

(2) The undetected TC Transfer Frame error rate shall be less than one undetected Transfer Frame error per 10^9 frames that are transmitted. This shall be achieved under all conditions where the bit error rate provided by the layer below is better than $1x10^{-5}$.

These operating points have been chosen to ensure that the COPs defined in this Recommendation may operate at high efficiency.

The service described in this Recommendation is designed to support the TC Data Management Service, particularly the TC Packetization layer, but it can also provide services to other non-standard higher layer TC processes as long as the interface requirements of the TC Transfer layer are satisfied.

B-3.1 Transfer Layer: Sending End Service Specification

(1) INPUTS

From the layer above:

(a) User data structures which have been broken into TC User Data Units (e.g., TC Segments) that are compatible with direct insertion into a TC Transfer Frame data field.

(b) Control instructions, contained in a CCSDS standard data interchange structure.

From the receiving end of the layer:

(c) Information concerning the status of receipt of individual TC Frames, formatted into a Command Link Control Word (CLCW) and extracted from standard Telemetry Transfer Frames.

From the layer below:

(d) Status of the physical channel.

(2) OUTPUTS

To the layer above:

(a) Status of the data routing process, including the progress of delivering individual TC User Data Units and the availability of Virtual Channels.

To the receiving end of the layer:

(b) "Control Command" TC Transfer Frames which instruct the receiving end how to accept and report the received frames.

To the layer below:

(c) Buffers of TC data bits containing protocol data units from the TC Transfer layer (e.g., one or more TC Transfer Frames).

(d) Control instructions defining the operational procedures to be used to transmit the buffer of bits to the spacecraft.

(3) INTERNAL FUNCTIONS

(a) Encapsulates TC User Data Units (e.g., TC Segments) into TC Transfer Frames.

(b) Translates control instructions received from layers above into the appropriate set of operational procedures to be used to transfer the TC Frames to the spacecraft, including selection of the correct Command Operation Procedure (COP).

(c) Creates Control Command TC Frames for transmission to the receiving end of the layer in order to select the proper frame acceptance and reporting parameters.

(d) Supervises the transfer of TC Frames to the receiving end by executing a Frame Operation Procedure (FOP) in accordance with the selected COP.

(e) Retransmits TC Frames as required to rectify channel-induced errors.

(f) Responds to control instructions from layers above to abort command transmission by issuing the appropriate set of control instructions to the layer below.

B-3.2 Transfer Layer: Receiving End Service Specification

(1) INPUTS

From the layer above:

(a) Information defining the ability of the layer to accept more data (optional).

From the sending end of the layer:

(b) Control Command TC Transfer Frames which contain instructions defining how the data-carrying TC Frames are to be processed.

From the layer below:

(c) "Clean" octets of decoded TC data. (Note: only correct data, which have passed the decoder quality check, will normally be received.)

(d) "Data Start" signal (indication of the start of the first valid octet of TC data).

(e) "Data Stop" signal (indication of the last valid octet of TC data). (Note: trailing octets of "Fill" data could be present just before the Data Stop signal is received.)

(f) Control information describing the status of the physical channel (e.g., rf and bit synchronization).

(2) OUTPUTS

To the layer above:

(a) TC User Data Units (e.g., TC Segments) which have been extracted from TC Frames that passed the validation and acceptance tests, complete, in sequence and without omission or duplication.

To the sending end of the layer:

(b) CLCWs which will be utilized by the FOP to control the transmission of additional TC Frames, or the retransmission of previously sent frames, in accordance with the rules of the governing COP.

To the layer below:

None.

(3) INTERNAL FUNCTIONS

(a) Responds to Control Command TC Frames received from the sending end of the layer and selects the proper frame acceptance and reporting parameters.

(b) Supervises the acceptance and reassembly of TC Frames transmitted by the sending end of the layer, by activating the appropriate Frame Acceptance and Reporting Mechanism (FARM) in accordance with the selected COP.

(c) Creates reports (CLCWs) to the sending end describing the status of TC Frame acceptance, including identification of frames which were rejected or missing, in accordance with the rules of the governing COP.

(d) Processes TC Frames which have been retransmitted as required to rectify channel-induced errors.

(e) Reassembles sets of TC Frames into their intended sequence and extracts TC User Data Units (e.g., TC Segments).

(f) Passes the extracted TC User Data Units to the layer above.

(g) Responds to control instructions from layers below to abort command transmission by ceasing the processing of the current TC Frame, and awaiting new control instructions.